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DE LA COOPÉRATION INTERNATIONALE DANS LES INVESTIGATIONS GÉOLOGIQUES[1]

On a reproché à la Géologie, et ce reproche a surtout été fait par les personnes versées dans les sciences exactes, de se contenter de mesures approchées et de baser ses conclusions sur des notions parfois discutables. Il ne faut pas s'émouvoir outre mesure de cette critique ; la précision mathématique ne paraît pas conciliable en effet avec notre connaissance actuelle de la nature des choses; nous ne les pénétrons encore que d'une façon approximative, et c'est sagesse à nous, de nous garder de conclusions rigoureuses trop absolues, quand notre raisonnement ne repose que sur des prémisses insuffisamment établies.

Depuis un siècle, de louables efforts ont été tentés pour faire entrer la géologie dans la voie des sciences expérimentales, des sciences exactes. Nous devons une grande reconnaissance à James Hall qui ouvrit la voie, et à tous ceux qui l'ont suivi, et parmi eux, aujourd'hui que nous sommes en France, réunis à Paris, c'est vers Daubrée, le maître et l'ami distingué, que remontent nos pensées ; car sa place est marquée pour toujours, dans nos annales, comme celle d'un des grands pionniers de la géologie expérimentale.

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Beaucoup a été fait sans aucun doute déjà pour soumettre les faits observés à des mesures précises, et pour les contrôler expérimentalement dans les laboratoires, mais il serait puéril de ne pas reconnaître qu'il reste encore beaucoup plus à faire. On peut même prévoir que c'est de ce côté que se produiront les découvertes les plus fécondes, les progrès les plus décisifs. Jusqu'ici, les efforts tentés ont été individuels, exécutés indépendamment par des savants de divers pays, marchant parallèlement dans la carrière, sans profiter, ou sans s'aider, de ceux qui travaillaient à côté. Aujourd'hui nous nous demanderons s'il ne serait pas opportun d'envisager la possibilité d'une entente, l'organisation d'une coopération internationale plus large et systématique, dans cet important domaine de recherches scientifiques? Et il nous semble que les Congrès géologiques internationaux soient naturellement indiqués pour faire aboutir pratiquement et assurer le succès d'une tentative de ce genre.

C'est une voie un peu nouvelle pour nos Congrès, mais pas complètement neuve cependant. On trouve en effet, déjà, dans leur passé, cette même tendance à une coopération méthodique des investigations géologiques; tels sont la création de notre Comité de la Carte géologique d'Europe, notre Commission des Glaciers et celle de l'Observatoire flottant. L'idée a déjà été lancée, puisque nos commissions fonctionnent; mais nous croyons qu'elle peut être généralisée et devenir d'une grande fécondité. Déjà l'an passé, à Douvres, dans mon discours présidentiel, devant la section géologique de l'Association Britannique pour l'Avancement des Sciences, et dans une occasion où les géologues anglais avaient le plaisir de recevoir un si grand nombre de leurs confrères de France et de Belgique, j'ai touché cette question, et exprimé l'espérance de la porter cette année devant le Congrès géologique international réuni à Paris. C'est ce projet que je réalise aujourd'hui, en vous soumettant les remarques qui suivent. Il m'a semblé que nulle occasion ne serait plus favorable que celle-ci, où tant de géologues, délégués de tous les points du globe, se trouvent réunis, pour parler au Congrès de son but même, et de la direction à donner à ses efforts pour développer sa bienfaisante

influence et servir la cause de la science à laquelle nous avons consacré nos vies. Le Congrès, en raison même de son caractère international, a les moyens, mieux que toute administration, d'organiser et de guider les recherches géologiques ; et on peut affirmer que s'il est possible d'aboutir pratiquement dans cette tentative de coopération et de coordination, on le devra au Congrès qui l'encouragera et la patronnera.

Dans l'état actuel de nos connaissances, nul ne peut travailler dans le vaste champ de la géologie dynamique, sans reconnaître la nécessité impérieuse et croissante d'un plus grand nombre de mesures de précision, sans souhaiter des recherches expérimentales rationnelles ; par là, cet important chapitre de la géologie gagnerait en précision et en exactitude, et son progrès serait assuré. On a déjà beaucoup fait dans cette voie, il est vrai, mais mon sentiment néanmoins est que la géologie expérimentale en est encore à ses débuts. Nous ne devrions avoir de trêve, que tous les phénomènes géologiques susceptibles de ce genre d'investigations, n'aient été mesurés avec précision, ou expliqués par des expériences de laboratoire. Trop souvent, et dans les diverses branches de la géologie, nous nous contentons de l'observation plus ou moins précise et exacte sur le terrain, quand nous pourrions la contrôler et étendre sa portée par des déterminations précises, par des données numériques, qui fourniraient des bases exactes aux déductions théoriques et pratiques.

Mais le sujet ainsi compris est trop vaste pour être envisagé ici dans son ensemble. Je me bornerai à quelques examples pris dans les deux grands groupes de phénomènes de la dynamique géologique : ils me permettront d'arriver à mon but.

Voyons d'abord les mouvements et changements qui s'accomplissent à l'intérieur du globe, et qui sont généralement désignés comme *hypogènes*. Il est évident que beaucoup de ces phénomènes pourraient être observés et enregistrés avec plus de soin et de régularité qu'on ne l'a fait jusqu'ici. Les recherches du professeur George Darwin, et d'autres auteurs, ont appris combien étaient constants, bien que petits, mais mesurables, les tremblements auxquels la croûte terrestre était assujettie. On

doit se demander si ces trépidations sont en relation avec quelque lent déplacement de la croûte terrestre, et dans ce cas, quelle est leur résultante sur le niveau de la surface, dans l'intervalle d'un siècle ?

Un autre fils de l'illustre Darwin a établi récemment un appareil enregistreur sur l'une des lignes de dislocation du sol du sud de l'Angleterre, cherchant à constater s'il se produisait des mouvements du sol, de l'un ou l'autre côté de cette ligne de division. Des instruments de ce genre seraient avantageusement installés dans d'autres pays, notamment dans les régions affectées d'importantes failles récentes. Il serait important et intéressant de reconnaître si, à la suite d'un tremblement de terre, il s'est produit quelque dénivellation, de part ou d'autre d'une de ces failles.

Les tremblements de terre ont été l'objet de nombreuses études, et cependant il s'en faut beaucoup que nous possédions une explication suffisante et adéquate de la cause du phénomène. Dans la plupart des cas, d'ailleurs, ils n'ont été étudiés que lorsqu'ils avaient cessé de se faire sentir ; et l'installation d'appareils enregistreurs, de séismographes, a donné une clarté et une précision nouvelles à nos conceptions concernant la nature de ces mouvements. Ces observations, toutefois, ne pourront donner de résultat satisfaisant que lorsqu'elles auront été poursuivies sur de vastes espaces et pendant de longues périodes. Déjà l'Association Britannique pour l'Avancement des Sciences a fondé une Commission Séismologique ; ses instruments enregistreurs fonctionnent en plusieurs parties du monde et servent la science, sous l'inspiration de M. Milne. Le Japon a déjà fait beaucoup dans cette voie et nous sommes fondés à attendre de nouveaux services du Survey Vulcanologique, dirigé par le professeur Koto. Le Congrès géologique international pourrait voir s'il ne serait pas possible d'installer un autre Survey semblable, en quelque autre pays exposé aux tremblements, et il pourrait chercher à unifier les observations relevées dans les divers pays ; il fournirait de la sorte un fonds solide et bien documenté à toutes les dissertations sur les tremblements de terre.

Les relations des tremblements de terre avec la formation des montagnes sont également susceptibles d'être élucidées par des mesures exactes. Les secousses séismiques, si frequentes suivant les chaînes de montagnes, doivent-elles être considérées comme la continuation et la suite des processus qui ont déterminé la formation de ces chaînes? Et ces déplacements, dans quel sens s'opèrent-ils, ont-ils pour résultat un mouvement d'élevation ou d'affaissement? Nous ne pouvons actuellement répondre à ces questions, mais leur solution se présentera d'elle-même, le jour où nous aurons soumis les phénomènes séismiques à des mesures précises. Des mouvements et déplacements, insensibles à l'œil de l'observateur, seront mis en évidence par des séries répétées de mesures d'altitude minutieuses, au dessus d'un repère bien choisi. Ces chiffres s'ils étaient d'une exactitude absolue, permettraient par exemple de déterminer, s'il s'est produit, en quelque point, un changement d'altitude, après un tremblement alpin. Avec de semblables données, nous serions en mesure de fixer si la grande ride terrestre des Alpes, continue encore à s'élever ou si au contraire elle s'abaisse, et nous pourrions indiquer la vitesse du mouvement. Si ces mouvements sont lents, trop lents pour être appréciables aux sens de l'homme, depuis qu'il observe, c'est une raison de plus pour les mesurer exactement, comme des phénomènes continués pendant des périodes immenses.

Ces mesures ne nous apprendraient pas sans doute si les chaînes de montagnes sont nées dans une convulsion gigantesque, ou si elles se sont dressées en plusieurs fois, par des soulèvements répétés, ou enfin si elles se sont élevées tranquillement d'un mouvement lent et continu? Mais elles nous mettraient au moins en possession d'informations suggestives, sur la vitesse des mouvements d'oscillation de la croûte terrestre.

D'autre part, il est bien certain que le genre d'observations nécessaires pour obtenir ces résultats ne saurait être une œuvre personelle. Pour l'entreprendre et pour aboutir, il faudrait s'assurer le concours d'un ensemble de collaborateurs espacés sur toute la longeur et sur les deux versants d'une grande chaîne

montagneuse. Leurs observations devraient se poursuivre suivant un plan uniforme, méthodique, convenablement mûri, qui laisserait à chacun l'indépendence de ses efforts individuels, mais assurerait la communauté de but. Il nous paraît que l'organisation et le contrôle d'une entreprise de ce genre fournirait un but élevé d'activité à un Comité du Congrès géologique international.

Il y a une autre branche de géologie dynamique, une autre série de mouvements hypogènes dont les Congrès internationaux pourraient encore s'occuper avec succès ; et j'ai ici l'assurance de mon expérience personelle. C'est la question souvent disputée de l'origine des cordons littoraux ou plages soulevées, si caractéristiques des rivages marins du N. W. de l'Europe. Les géologues sont toujours aussi divisés relativement à l'origine de ces terrasses remarquables ; certains y voient des preuves d'abaissement du niveau de la mer, d'autres les considérant comme démontrant le soulèvement du sol continental. Il semble cependant qu'on ait négligé jusqu'ici de déterminer la condition fondamentale et essentielle, nécessaire à la solution de ce problème : de bonnes mesures.

Sans doute, on a des mesures locales, suffisamment précises et exactes, du niveau de ces plages, mais elles sont isolées et disséminées ; elles devraient au contraire être généralisées et étendues à de vastes régions, pour permettre des conclusions définitives. Il faudrait ici lever une série de nivellements rigoureux des plages soulevées, en les repérant exactement sur toute leur étendue, relativement à la ligne des côtes.

Ainsi, par example, en Ecosse, il y a deux de ces terrasses bien marquées, l'une à l'altitude d'environ 50 pieds, l'autre à environ 100 pieds, au-dessus du niveau actuel de la mer. Ces deux terrasses se retrouvent à E. et W. sur les deux rivages du pays, paraissant conserver les mêmes altitudes ; or, on n'a point encore fait de nivellement systématique qui permettrait de reconnaître la constance ou la variation de leurs niveaux, soit d'un côté ou de l'autre du pays, soit dans la direction du N. au S. — Ces deux terrasses disparaissent l'une comme l'autre,

au Nord, on ne les voit pas non plus au Sud, en Angleterre; on remarque en outre certaines inégalités apparentes de niveau, suivant leur parcours, ce qui semble indiquer qu'elles ont été sollicitées par des mouvements inégaux. Mais avant que ces différences aient été mesurées avec précision, je n'estime pas qu'un savant soit fondé, d'après ce qu'on observe en Ecosse, à conclure que le niveau de la terre s'est élevé, ou que celui de la mer s'est abaissé. J'espère que cette question spéciale sera élucidée chez nous, d'une façon satisfaisante, et j'ai déjà pris des dispositions à cet effet; mais sa solution ne suffira pas pour asseoir une conclusion générale. Elle devra être étudiée comparativement dans d'autres pays. Il serait désirable que sous l'impulsion et sous les auspices des Congrès géologiques internationaux, les géologues danois, norwégiens, suédois, finlandais, russes, écossais, américains, entreprennent d'un commun accord un lever détaillé, qui fixe, d'une façon définitive, ce problème des lignes littorales de l'hémisphère boréal.

Je passerai maintenant à la considération de quelques exemples choisis dans l'autre classe de la dynamique géologique, parmi les *phénomènes épigènes;* là encore on trouverait de grands avantages à généraliser les méthodes préconisées de mensuration et d'expèrimentation.

L'ètude des phenoménes de dénudation nous ouvrira un champ illimité, quoique de toutes parts déjà il ait été défriché avec activité et avec succès. Des volumes, des mémoires, des articles de toute forme, ont été consacrés à l'étude de ces phénomènes de dénudation; et cependant, dans cette riche littérature, il y a pauvreté assez générale de précision, absence presque constante de résultats numériques, rareté des mesures exactes, systématiques ou continues, en un mot défaut habituel des données qui permettraient de se rendre un compte véritable de l'étendue et de la rapidité des dénudations observées. Il y a toutefois des exceptions honorables, et nous possédons bien quelques mesures exactes de la plus haute valeur, et leur nombre s'accroît encore tous les jours, mais quel avantage il y aurait, pour la science, à le décupler!

C'est qu'en effet quand on envisage la sculpture et les formes d'altération des traits terrestres sous l'influence de la dénudation, il semble qu'il y ait cent moyens de contrôler l'observation immédiate des phénomènes, par des mesures directes, ou par des expériences de laboratoire.

C'est presque un lieu commun de dire, en géologie, que la quantité de substances enlevées en suspension ou en solution par les cours d'eaux, mesure l'importance de la dénudation des régions drainées par ces rivières. Et cependant combien inégales, et combien insuffisantes en général sont les indications numériques que nous possédons sur cette importante question! On n'a encore étudié systématiquement, à ce point de vue, qu'un très petit nombre de rivières, et les résultats discordants ne peuvent être considérés comme définitifs. Ils ont suffi seulement à montrer l'intérêt et toute l'importance de cette méthode de recherche; mais on n'est pas encore en possession de documents suffisants pour en tirer des déductions rationnelles, moins encore des généralisations.

Ce qu'il nous faudrait pour cela, c'est une série d'observations bien menée, organisée suivant un plan uniforme, poursuivie pendant plusieurs années, et étendue à toutes les rivières d'un pays, voire même à toutes les grandes rivières des divers continents, loin d'être limitée à un seul cours d'eau. Il importerait de connaître, aussi exactement que possible, l'étendue et la surface du bassin des rivières, les relations de leur débit avec les quantités de pluie, le détail de toutes les conditions météorologiques aussi bien que des topographiques, les variations dans les proportions des matières suspendues ou dissoutes dans leurs eaux, relativement aux formations géologiques traversées, à la forme du fond, à la saison, au climat. En un mot, il faudrait connaître en détail le régime de toutes les rivières. On peut citer, comme modèle du genre, l'admirable rapport de MM. Humphreys et Abbott, sur les "Physics and Hydraulics of the Mississippi" publié en 1861, bien que ces auteurs, préoccupés de diverses questions étrangères à la géologie, aient laissé dans l'ombre certains points d'un grand intérêt pour nous.

Ce que nous avons dit de l'étude des Rivières s'applique exactement à celle des Glaciers. Il semble, il est vrai, que les lois qui régissent le mouvement des glaciers aient été amplement approfondies, et qu'on ait relevé avec soin leurs mouvements d'avance et de retrait. Mais ce sont des côtés de la question plus intéressants pour le physicien et le météorologiste. Nous, nous devons réclamer, comme géologues, des informations plus précises sur le labeur géologique des Glaciers. Il nous importe de mieux connaître la vitesse avec laquelle ils creusent leur voie, les circonstances qui favorisent ou retardent leur puissance érosive, les conditions qui leur permettent de remonter des pentes, et enfin la réalité et l'importance des mouvements, en sens divers, qui se produisent dans la glace, et par suite desquels les cailloux sont charriés et les stries sont orientées dans des directions variées. Ce sont autant de questions, et il en est beaucoup d'analogues, sur lesquelles nous ne possédons que des renseignements vagues et incertains. Il semble cependant que leur solution dépende d'une série d'observations systématiques, suffisamment prolongée, à condition qu'elles ne soient pas bornées à la Suisse, mais poursuivies en Scandinavie, dans les Régions arctiques et antarctiques, aux Indes, à la Nouvelle-Zélande. Notre Congrès International a déjà marché dans cette voie, et créé un Comité des Glaciers qui, sous l'impulsion enthousiaste de M. Forel, a déjà rendu des services signalés. Ce Comité est digne que nous nous intéressions à lui et que nous encouragions ses efforts, il y aurait avantage à le développer, pour qu'il étende son action à toutes les régions du globe accessibles aux géologues. Ainsi les savants danois qui, dans ces dernières années, ont tant ajouté à nos notions sur les glaciers et les nappes glacières du Groënland, les géologues américains qui ont fait de si bon ouvrage parmi les glaces de l'Alaska, seraient d'excellentes recrues pour notre Comité des Glaciers; et il y a lieu de croire qu'il suffirait d'une simple invitation pour qu'ils poursuivissent de concert avec nous, les mêmes recherches systématiques.

Un autre sujet d'étude qui a attiré à maintes reprises l'attention des géologues, est celui de la Dénudation Subaérienne de la

croûte terrestre. Et cependant nous manquons aussi de documents précis ; on n'a pas encore mesuré son action comparativement, avec précision et méthode, sur les différentes roches, et sous diverse climats. On pourrait s'aider dans cette mesure de l'examen de bâtiments, portant la date de leur construction ; j'ai pu ainsi indiquer, il y a déjà 20 ans, la rapidité de la désagrégation de certaines roches dans un climat humide et variable comme celui de l'Ecosse. On a cependant jusqu'ici peu fait, dans cette voie.

L'étude de la dénudation ne peut guère se séparer de celle de la sédimentation : les matériaux déposés par la sédimentation sont ceux qui on été enlevés par dénudation, moins ce qui a été dissous en route, dans les eaux des ruisseaux ou de la mer. Or, il nous reste beaucoup à apprendre sur les conditions de la sédimentation, et ses variations de vitesse.

Il ne semble pas qu'on puisse compter sur de notable progrès dans cette étude, aussi longtemps qu'on ne l'abordera pas systématiquement, au moyen d'un plan préconçu, bien mûri et poursuivi avec continuité. Il y a encore bien des inconnues pour nous, dans la forme et la rapidité des dépôts qui s'accumulent sous l'influence des divers facteurs, dans les lacs, les estuaires et la mer. Ainsi nous ne saurions indiquer par une moyenne, la vitesse avec laquelle se comblent les lacs des divers pays d'Europe. Si d'ailleurs nous connaissions cette vitesse, et si nous savions, d'autre part, la quantité de sédiments déjà amassée, nous aurions en notre possession un moyen de calculer, non seulement en combien de temps ces lacs seront comblés et disparaîtront, mais aussi, ce qui est plus important, depuis combien de temps leur remplissage se poursuit. Ce chiffre en effet, nous fournirait une date, pour la fin de la Période Glaciaire. Des conclusions de cette nature ne sauraient découler d'observations isolées ou locales, elles doivent être basées sur les observations combinées de nombreux observateurs, des diverses régions lacustres du continent, suivant un plan déterminé.

La géologie est entrée dans une période où on doit attendre les plus grands avantages de méthodes d'investigation plus précises, de la convergence des efforts individuels, librement associés

sous une même règle, et vers un même but. Il serait aisé d'en multiplier encore les exemples. Mais nous croyons en avoir dit assez, pour faire voir au Congrès la portée de ces tentatives, et l'importance que nous y attachons. Nous ne proposerons pas toutefois ici de plan général d'organization, notre intention actuelle étant de nous borner à une sorte de consultation, et de demander à nos confrères s'ils pensent avec nous qu'il serait bon, avantageux, et praticable d'installer sur des bases plus larges la coopération en géologie? J'estime que nous aurions rendu un service durable à la science, si nous arrivions à grouper des observateurs en comités d'action, travaillant avec méthode, vers un but déterminé, soit l'un de ceux que je viens d'indiquer, ou tout autre. Il y aurait même de la prudence à débuter par la question la plus facile, celle qui réclamerait la moindre dépense d'hommes et d'argent. On pourrait partager la besogne, entre les divers pays représentés au Congrès. Chaque pays pourrait librement choisir le sujet de ses observations, n'étant poussé que par l'émulation de voir ses voisins avancer dans la même voie.

Un Comité Central composé de members des diverses nations engagées dans ces recherches sur le terrain, rendrait des services en traçant les méthodes générales, les plans de travail, et en indiquant le but. Son rôle se bornerait à organiser le travail et à généraliser la méthode, en laissant la plus grande latitude possible aux efforts individuels.

La publication des résultats ne serait pas non plus soumise à l'appropriation du Congrès Chaque collaborateur, chaque comité resterait libre de suivre ses convenances, et on se bornerait à présenter à nos sessions, tous les trois ans, un aperçu sommaire des résultats généraux. Nous avons la confiance que ces résumés, publiés par nos Secrétaires et insérés dans nos Comptes-Rendus, constitueraient un des chapitres les plus importants de nos volumes triennaux. L'idéal d'une assemblée comme la nôtre ne saurait être de contrôler le progrès, mais bien de l'encourager, et de favoriser le groupement et l'association de toutes les initiatives internationales.

ARCHIBALD GEIKIE.

PROPOSED INTERNATIONAL GEOLOGIC INSTITUTE[1]

IT is a source of profound regret that imperative circumstances prevent my attendance at what I am sure will be a most important session of the International Geological Congress. Forbidden this pleasure, I venture to show my interest by offering some suggestions relative to a line of effort tributary to the leading purpose of the congress. At the first session of the congress in 1878, which I had the pleasure of attending, a dominant theme of discussion was geologic classification, and this continued to be the foremost theme for subsequent sessions until it was found impossible to agree upon any system proposed. It furthermore developed that many of the most able and experienced geologists were of the opinion that it was premature to attempt any authoritative action in the matter, since in their judgment the groundwork for a *permanent* classification was not yet sufficiently broad and firm, and they felt much apprehension respecting the trammeling effects of sanctioning a premature classification. Thoughtful geologists who have given the matter careful study will quite generally agree that much is yet to be learned of fundamental facts and principles before a classification can be authoritatively adopted as the mature judgment of the geologists of the world without great risk of hampering the progress of true classificatory ideas. It seems not unlikely, therefore, that an authoritative adoption of a general classification will continue for some time to be regarded as a great end to be ultimately reached, but not wisely attempted until the foundation is better laid.

In the meantime, what can be done to hasten the great achievement?

A true classification of geologic history must represent its *natural* divisions, if there be such natural divisions. In the judgment

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of some geologists there are no natural divisions that hold good beyond limited provinces. They recognize no general divisions of a sufficiently definite kind to serve the purposes of a concrete classification. In their judgment the succession of geologic events was a continuous progression. They admit that it was differentiated locally and even continentally, but not so universally as to furnish a good basis for classification. They recognize that the existing classifications are natural in some degree as applied to Europe and America, the regions upon which they have been founded, but they anticipate that they will prove quite arbitrary as applied to other continents and to the world as a whole. Entertaining these fundamental views, they hold that classification should be regarded merely as a convenient arbitrary device, and that the existing systems should give way to a more convenient one, much as the old systems of measurement are giving way to the metric system.

On the other hand, there are those who regard the history of the earth as naturally divisible into important stages whose recognition constitutes a leading function of philosophic geology. None of these contend that there was at any time a universal cessation of sedimentation or a complete break in the continuity of life. They freely admit and affirm that there is a fundamental continuity, but at the same time they hold that progress was not uniform, but pulsative or rhythmical. Specifically, speaking for some of these, they think they find periods of stress-accumulation followed by periods of stress-relief, periods of land-expansion followed by periods of sea-transgression, periods of topographic accentuation followed by periods of base-leveling, periods of climatic uniformity followed by periods of climatic diversity, periods of biologic luxuriance followed by periods of biologic impoverishment, in short, a pulsative progress whose successive phases furnish a natural basis for classification.

The existence of these diverse views is an expression of the imperfection of present knowledge. Were exhaustive data at command it could be determined whether the dominant character of the earth's progress was uniformity or periodicity, and hence

whether we should primarily seek a scale of reference and nomenclature with a uniform arbitrary unit, as the meter or the century, or whether we should strive to measure progress by its inherent waves or nodes, or whether we should seek both impartially.

If the rhythmical view be the most laudable, effort should be directed to the more complete and accurate determination of the nature and limits of the periodicities, and to the modification of present classification, so as to bring it into more complete conformity to these. If the uniformity view be the more laudable, effort should be directed to reducing the adopted divisions to quantitative equality by perfecting the geological column and determining available scales of measurement, both stratigraphic and chronologic.

In either case, or in any other case which any individual geologist may prefer to put in the place of these selected ones, it is necessary to push investigation a long way forward before an International Congress can wisely give its sanction to any specific classification.

Our shortest road to the great end sought will therefore be found in promoting those investigations which will soonest give the needed groundwork. Fortunately these investigations are precisely those which best subserve the higher philosophic purposes of the science. Two phases of this great work stand forth prominently: (1) The systematic compilation and elaboration of the great mass of data produced by studies in all parts of the world, which are not now fully available, save to a few favored workers connected with the great libraries, and to these only through much labor duplicated in every individual case. It will be admitted without discussion that the collocation and organization of existing and forthcoming data would greatly stimulate accretions and promote the end sought. (2) *The development of additional criteria of correlation. A preëminently essential step in the progress of classification and interpretation is an increase in the precision and the certainty of correlation of formations in widely separated regions.*

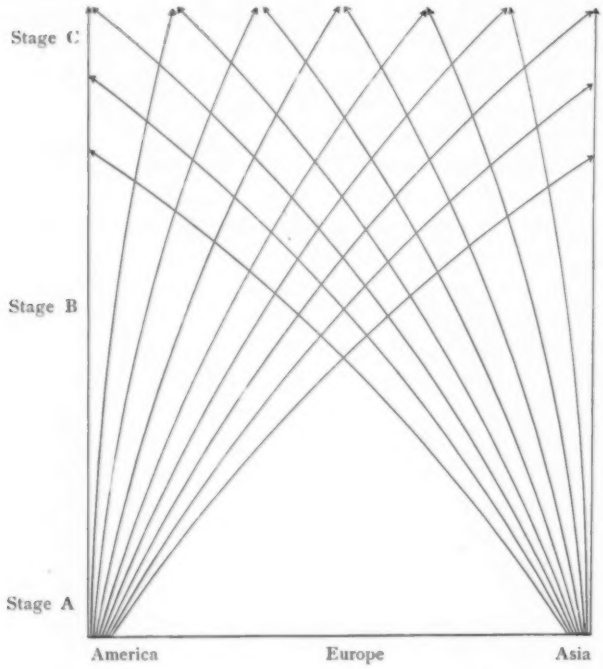
At present the general conviction prevails that there is but a single trustworthy basis of correlation between separated regions, and that even this is subject to some important qualifications, and in many cases is wholly unavailable. I need not mention fossil contents. But while fossils are, and apparently must ever remain, the chief means of correlation, it has been the growing conviction of my recent years that certain important improvements and extensions of the criteria of correlation are possible. These embrace (*a*) an improvement of the paleontologic criteria by correcting them for the uncertainties and errors introduced by migration; and (*b*) the addition of physical criteria to the paleontologic ones in such a way as to eliminate some of the uncertainties of the latter, and to serve in their place when they are not available, as is so often the case.

It is neither appropriate nor possible to set forth these adequately here, but I should fail to duly magnify the importance of the measure herein advocated if I did not at least try to indicate the greatness of the possibilities which we might hope to realize if we had the means at our command.

(*a*) The line of improvement in paleontologic correlation may be best illustrated by a concrete example. Let it be supposed that a provincial fauna arises in a harbor of refuge during a time of sea-withdrawal from the continental shelf[1] on the border of America in a given stage A; that by the subsequent development of an adequate sea-shelf or a connecting series of epicontinental seas, this fauna migrated to the shores of Europe during stage B, and that ultimately it reached the coast of Asia in stage C. By the simple application of the criterion of community of species, stage C of Asia would be correlated with stage A of America, and although the time-interval might not be very great, the error growing out of it might seriously disconcert the correlation of associated physical events, and prevent their correct interpretation. But if during the stage A there developed in a harbor of refuge on the coast of Asia another provincial

[1] "A Systematic Source of Evolution of Provincial Faunas," JOUR. GEOL., Vol. VI, No. 6, Sept.-Oct. 1898, pp. 604–608.

fauna, and if this, for like geographic reasons, was permitted to reach Europe in stage B, and America in stage C, a different set of errors of interpretation would be likely to arise from the simple criterion of community of species, for the commingled faunas would appear in America and Asia only in stage C, while they would appear in Europe as early as stage B. So too, in



America and Asia, in stages A and B, only the respective provincial faunas would be found. The situation is illustrated in the accompanying diagram. But if the fact of the provincial origins of the two faunas and their subsequent migration can be established, a much more accurate correlation will be possible. The deposits of stage A in Asia and America will be correctly

assigned to the same period, though they have no species in common, and the other stages will fall into their proper sequence. This may suffice to illustrate one method by which the migration, *and particularly the cross-migration*, of faunas may be brought into service in the correction of the errors of correlation arising from dependence simply on the presence of common fossils. It will furthermore be recognized with acclaim that the tracing out of the origins and migrations of the ancient races of the earth's inhabitants has independent and profound interest, and that it is peculiarly and necessarily an intercontinental work.

But the origin and migration of faunas and floras is peculiarly dependent on physical conditions. I am persuaded that this is most eminently true of the origin of provincial faunas and their evolution into cosmopolitan faunas, as I have endeavored to set forth in recent papers.[2] While it will doubtless always be quite difficult to detect the point of origin and the course of migration of *single species*, there is reasonable ground of hope that the origin of provincial *faunas* may be located, and their migrations and fusions followed until they are lost in cosmopolitan faunas. I have given reasons elsewhere for believing that the general production of provincial marine faunas of the shallow-water type is connected with the withdrawal of the sea from the upper face of the continental platforms, associated with surface warpings, by the first of which the areas of shallow water are restricted, and by the second dissevered from each other.[3] It is therefore believed that much aid in rendering paleontologic interpretations more significant, more certain, and more precise may be derived from the study of the bodily movements of the earth and of the evolution of the geography of the continents in their migratory relations. Certainly and admittedly

[1] "The Ulterior Basis of Time Divisions and the Classification of Geologic History," JOUR. GEOL., Vol. VI, No. 5, July-August 1898, pp. 449–526.

"A Systematic Source of Evolution of Provincial Faunas," JOUR. GEOL., Vol. V, No. 6, Sept.-Oct., 1898, pp. 597-608.

"The Influence of Great Epochs of Limestone Formation on the Constitution of the Atmosphere," *Ibid.*, pp. 609–621.

[2] The first two papers above cited.

this is eminently true of land faunas whose migrations are essentially dependent on terrestrial connections, and I believe it is scarcely less true that the migration of the more immobile portion of shallow water sea faunas is dependent on continental shelves and epicontinental seas. If, therefore, there be a periodicity in the great bodily movements of the earth and sea, and a consequent periodicity in the origination of provincial faunas, there will be all the greater field for the application of principles founded on migration and counter-migration to the working out of more precise correlations.

(*b*) There is reason to hope that the sea itself may be made an important aid in intercontinental correlation, for it makes, and always has made, *a simultaneous record on all the continents*. The difficulties lie solely in reading the record.

The ocean volume may not have been accurately constant at all times, but its variations between closely related periods can never have been more than a negligible fraction of the whole volume. Its record is made on the border of a single complex basin, for all the oceans are united and have a common water level. Apparently there has always been essentially a single complex basin, though this cannot be rigorously affirmed. Assuming it, however, any deformation of the basin in any part, which affects its capacity, is recorded on all continents by a new shore line. Setting aside compensatory warpings, this involves a universal advance or retreat of the sea, and a corresponding change in the areas of sedimentation and erosion. It involves, also, a change of land and sea faunas by expanding and contracting their habitats respectively, and by extending or restricting their means of migration. Were it not for the attendant warpings of the land, these sea changes would furnish a simple means of world-wide correlation of the most precise and specific kind. Conjoined with paleontology they would leave little to be desired so far as marine stages are concerned. There remains, however, the problem of eliminating the disturbing effects of concurrent warping. To some large extent it is the warping that changes the capacity of the ocean basins. Warping may even disturb

the local attitude of the land to the sea without affecting the capacity of the ocean basin, for the warping up in one region may be compensated by the warping down in another region. The subject is therefore attended by grave difficulties, but it is not without sufficient ground of hope to justify systematic study. There are at least two general phases of earth-action whose effects promise to rise above those of local warpings to such a degree as to be determinable and to be serviceable in intercontinental correlation. They are the stages of great shrinkage and the stages of relative quiescence. Whatever views may be entertained of the early history of the earth or of its internal constitution, it will probably not be questioned that the oceanic bottoms have, on the whole, shrunk more than the continental platforms. The very existence of the continents in spite of erosion is an expression of this. It will perhaps not be denied that the shrinkage adjustments of the exterior of the earth have been periodic and that the basins have been deepened and the land relatively elevated at the periods of adjustment; at any rate, this may be made a working hypothesis, coördinately with its opposite, until the truth is ascertained.

Between the assumed periods of adjustment, periods of relative quiescence may be recognized as their necessary complement. These were only relatively quiescent, for local and regional warpings were quite certainly in progress at all stages of geological history. In these stages of relative quiescence the volumetric erosion of the land may quite safely be assumed to have exceeded the volumetric elevation, and the material transported to the sea may be assumed to have exceeded any increase of the capacity of the ocean basin due to shrinkage. Without these assumptions it seems to me difficult to explain specifically the history of erosion and sedimentation; but, as this may be doubted, let the assumptions stand merely as working hypotheses. The result of such erosion would be the partial filling of the common ocean basin and the extension of the sea upon the land. Taking Murray's estimate of the present average height of the land, a volumetric reduction and transference of one half

the protruding portion would raise the sea level somewhat more than one hundred meters, an amount sufficient, in the lowered state of the continents, to notably extend the marine area and change the distribution of life.

Here, then, hypothetically are two systematic causes tending to produce universal changes in the relations of sea to land, the one dependent on the accumulation of shrinkage stresses by reason of the effective rigidity of the earth, and the other dependent upon erosion during relatively quiescent stages. Now, if by the compilation of great masses of data the disturbing effects of local warping can be eliminated, a means of intercontinental correlation, independent of the paleontologic, and fundamental to it, may be obtained. By combining the dynamic with the paleontologic the testimony of both may be enhanced and the significance of the latter greatly increased.

The application of the method obviously requires the massing and handling, quantitatively as well as qualitatively, of all possible data from all parts of the world, and can only give results of the highest order of trustworthiness when the mapping of the whole earth approaches completion, but there is reason to believe that initial results of no small value might even now be secured if all existing data could be marshaled.

The constitutional states of the atmosphere furnish a third source of hope of supplementary means of correlation. If the view that the atmosphere originally contained all or the larger portion of the elements which have been taken from it, notably the carbon dioxide, and that its history has been one of continuous depletion, and that, aside from a slow decline in temperature, climatic changes have been due merely to local agencies, be correct, there is little ground of hope for results of much value in correlation. But if, on the other hand, as recently postulated,[1]

[1] A Group of Hypotheses Bearing on Climatic Changes. JOUR. GEOL., Vol. V, No. 7, October-November 1897.

The Influence of Great Epochs of Limestone Formation on the Constitution of the Atmosphere, JOUR. GEOL., Vol. V, No. 6, September-October 1898, pp. 609–621.

An Attempt to Frame a Working Hypothesis of the Cause of Glacial Periods on an Atmospheric Basis, JOUR. GEOL., Vol. VII, Nos. 6, 7, and 8, 1899.

the carbon dioxide of the atmosphere has been mainly supplied concurrently with its consumption, and the amount has varied with the ratios of supply to consumption, and these ratios have been dependent upon the extent of the land and the condition of the sea, and if further the impoverishment of the atmosphere in carbon dioxide is determinable by the unusual prevalence of certain kinds of deposits, as salt, gypsum, red clastics, and glaciated bowlder clays, while its enrichment is indicated by equable temperatures and mild climates in high latitudes, there is ground for hoping that the constitution of the atmosphere may be made to afford a valuable means of correlation applicable when the paleontologic criteria are most liable to fail. Effects due to the constitution of the atmosphere must be universal and strictly simultaneous, though of course not everywhere identical. For example, in India, Australia, and South Africa, an abrupt change in the flora took place at some time near the transition from the Carboniferous to the Permian period. Fontaine and White have found an abrupt, though less radical, change in the flora of eastern America at about the same time, but there are no paleontological means at present known by which these changes can be accurately correlated. The change in India, Australia, and South Africa is closely associated with glacial deposits. Now, if glaciation be a result of a *constitutional* state of the atmosphere, such state should make itself felt *in all parts of the earth simultaneously*, though in different ways and degrees, and the floral change in eastern America could with good reason be strictly correlated with the changes in Asia and the southern hemisphere, and should find verification in similar changes elsewhere. This is merely a hypothetical illustration. The supposed atmospheric mode of correlation should be verifiable by its peculiar effects, for it should simultaneously affect distant floras made up of different constituents, a phenomenon differing in nature from the effects of simple migratory replacement or biologic evolution.

It is obvious, however, that correlation by atmospheric states can only become a trustworthy dependence by the

massing and careful adjudication of data from all parts of the world, for the sanction of the method will largely depend on its success in conforming to and elucidating world-wide phenomena. Both this and the preceding method will require first to be established by trial before they can be independently applied, but this was equally true of the paleontologic criteria at the outset.

The very establishment of these atmospheric and oceanic criteria, or their disproof, would go far to settle the fundamental question whether the earth's history is naturally divisible into periods or not. If there be secular accumulations of stress in the body of the earth, followed by adjustments when rigidity is overcome, and if these adjustments change the respective areas of land and sea, and these in turn result in changes in the constitution of the atmosphere and in the evolution of life, these cycles must be factors in the ultimate basis of a rational classification of geologic time, and must at the same time express some of the most profound and significant features of the earth's history.

The doubt as to whether these things be so or not can only be resolved by studies as broad as the earth. Such studies are not only international and intercontinental, but they are omniterrestrial. The shaping they have been given here is that of an individual student and expresses his limitations, but the breadth and importance of the problems themselves will not be questioned.

Now it is far beyond the functions and the resources of any present official organization to adequately cope with these great problems. There is not even an organization at present that is provided with the men and the means to bring promptly together, arrange, and tabulate for the common benefit of geologists the data that are being gathered by official and private investigations; much less is there any organization that can build these into their organic relations, or draw forth from them their full significance and make this serviceable in further investigation. Nor is there any organization provided with any notable means

for systematically supplementing the work of official and private surveys where such auxiliary work is most needed. A few universities and a few generous individuals provide means for particular expeditions and these have great value and should command our profoundest appreciation, but they are not, and cannot be expected to be, systematically related to classification or to the other general questions under the special patronage of this body.

I beg to urge, therefore, upon the International Congress the inauguration of a systematic movement looking to the determination of the fundamental facts upon which an ultimate classification may be founded.

The practical suggestion I ask leave to offer is an appeal to the generous people of our several nations for the means to establish a permanent institute, or group of coördinate institutes, which shall be devoted to this purpose and to others germane to it. Specifically these purposes may be summarized as follows:

1. The collocation, systematic arrangement, and publication of existing and forthcoming data bearing upon the fundamental facts and principles upon which a final classification must be founded.

2. The gathering of literature, especially that now least accessible, and, so far as practicable, of typical collections bearing on the special objects of the organization.

3. The elaboration of data by combination, computation, and correlation, both independently of all hypotheses and in specific application to the various hypotheses that may be propounded.

4. The encouragement, and so far as practicable, the conduct of field investigations in regions not cultivated by existing organizations, nor reached by private enterprise.

The magnitude and duration of the work would require that the institution be permanent. If the task of the complete correlation of the earth's formations be assumed it is doubtful if the function would ever be entirely fulfilled.

The generosity with which great institutions of learning have been founded and expensive scientific expeditions equipped gives encouragement to the hope that if the noble object were suitably made known, the means for its realization would be forthcoming.

It may seem premature to discuss details of organization and modes of control before the general nature of the proposition is approved, or substantial encouragement be given that the necessary means of carrying it into effect will be available, but the practicability of the proposition is in some measure dependent on the concrete form which it would take. This is a peripatetic body of changing membership, and, so far forth, is not most happily organized to administer an enterprise of this kind. The congress, furthermore, represents many nations and could not be hoped to be entirely at one as to the location and control of a permanent institution of this kind. It is, furthermore, probable that patrons of the proposed organization would be influenced by patriotic sentiments in making contributions to the endowment. It seems best, therefore, to recognize these conditions in the proposition itself, and instead of endeavoring to establish a single international institution under the specific control of this body, to urge the establishment of sections or branches or coöperative members of a composite organization to be located in as many nations or grand divisions of the globe as future developments might render wise; these sections or branches to be immediately administered by such bodies in such nations or grand divisions as were found most suitable and practicable. For example, in America, a section or a coöperative institution might well be established under a board of trustees elected by the Geological Society of America, a permanent organization of definite membership, representative of geological activity on the North American continent. Similar representative societies or fixed geological organizations fitted for the control of other branches or coöperative institutions exist, or if not, should be brought into existence, in all the great nations or grand divisions. Such regional organizations would possess certain advantages in the

collection of data from the fields they would specially represent. The function of the International Congress would embrace the inauguration and coördination of these, the advisory control of their lines of effort, the adoption of their partial results as reached from time to time, and the creation of international sentiment in their support.

T. C. CHAMBERLIN.

UNIVERSITY OF CHICAGO,
July 25, 1900.

THE COMPOSITION OF KULAITE

SEVERAL years ago I published[1] as an inaugural dissertation an account of the volcanoes of Kula, in Lydia, Asia Minor. In this the recent lavas of the region were described, to which rocks the name of "Kulaite" was given, the definition being, "a subgroup of the basalts which is characterized by the presence of hornblende as an essential constituent, which surpasses the augite in quantity and importance." The varieties of leucite-kulaite and nepheline-kulaite were also recognized, the essential character of all being the predominance of hornblende over augite.

Although the analysis made for me by Dr. Röhrig showed, for basalts, abnormally high Na_2O, yet little attention was paid to this feature and, attempts at identifying nepheline in the groundmass having failed, the kulaites were regarded essentially as plagioclase-basalts in which the pyroxene was largely replaced by hornblende.

In his latest book, Rosenbusch[2] recognizes this combination of high alkalis with a basic combination, and refers them to his group of trachydolerites, an intermediate group corresponding to the latities of Ransome,[3] which are effusive equivalents of the monzonites and intermediate between trachytes and andesites or basalts.

Study of other rocks of Asia Minor, which also showed similar latitic features, as well as the growing importance of these intermediate types, also called my attention again to the Kula rocks, and led to a reëxamination of them. This seemed

[1] The Volcanoes of the Kula Basin, in Lydia, New York, 1894.
On the Basalts of Kula, Amer. Jour. Sci., Vol. XLVII, p. 114, 1894.

[2] ROSENBUSCH: Elemente der Gesteinslehre, p. 342, 1898.
It is uncertain whether Rosenbusch understood these rocks to be without any feldspar at all, or only without feldspar phenocrysts.

[3] RANSOME: Amer. Jour. Sci., Vol. V, p. 373, 1898.

especially needful chemically, since, as was pointed out to me by Professor Iddings, judging from the description published in 1894, there seemed to be no mineral present which would account for the high alkalis. In addition, for such basic rocks, Al_2O_3 seemed to be very high and MgO very low, and it was feared that Dr. Röhrig had made the common error of precipitating some MgO along with the Al_2O_3. I am happy to be able to say that two analyses, made by me with especial care in regard to this point, show conclusively that in this respect Röhrig's analyses are quite correct.

As the rocks have been already described, it is not necessary to go into any lengthy account of their mineralogical features, and only the two analyzed will be mentioned.

The rock from a depth of 35 meters in a well digging in Kula is light gray, fine grained and slightly vesicular, with small phenocrysts of olivine and pyroxene visible. In thin section phenocrysts of pale gray pyroxene (diopside), olivine and of hornblende, which last in every case have been completely altered to a mixture of diopside and magnetite, are seen lying in a holocrystalline groundmass. This is composed of bytownite laths, small crystals and anhedra of diopside, magnetite grains and small apatites, with an ill defined, colorless mesostasis of low refractive index and small birefringence, which was previously referred to accessory orthoclase.

The tests made in Leipzig failed to reveal the presence of nepheline, but these have been lately repeated with care, and they prove beyond question that part of this interstitial, anistropic substance gelatinizes with acid and stains with fuchsine, while part of it remains unaffected. It is therefore established that nepheline is present in this rock, a conclusion in accordance with the results of analysis, as will be seen later.

A second specimen to be described is of a "leucite-kulaite," from the northeast flow of Kula Devit,[1] near the Gediz-chai,

[1] This was spelled "devlit" in the former papers, following earlier authorities (Hamilton, Tschihatcheff) and as the word was apparently understood by the natives. It is really دويت "devit" an ink-stand, and not دولت "devlit" state or government. Cf. Inaug. Diss., p. 12.

Megascopically, this is similar to the other, but is darker gray and somewhat finer grained.

In thin section it shows fewer phenocrysts of diopside and olivine than the other, but more abundant, well-formed, hornblendes, which have all been altered, in some cases entirely, in others only partially, leaving some unchanged hornblende substance in the center. This alternation has not been as thorough as in the preceding, and, while here and there alteration to the usual diopside-magnetite aggregate is seen, in most cases the spaces formerly occupied by hornblende show a mass of the brown, pleochroic orthorhombic rods, which I have identified with hypersthene.

The groundmass is similar to the other, but flow structure is well marked. There are similar plagioclase laths (here andesine), also olivine and diopside crystals, generally stouter and better crystallized, and smaller grains of magnetite but scarcely any apatite. The most important difference is the presence in abundance of small round areas of a clear, colorless mineral, of low refractive index, and generally isotropic, containing inclusions of diopside needles and magnetite grains, arranged either centrally or zonally. While these round spots are mostly too small to show very marked abnormal double refraction, yet they occasionally do so, and there seems to be no doubt that they are to be referred to leucite. The mesostasis here is colorless and almost isotropic and glass-like, but it stains by treatment with HCl and fuchsine.

In the table are given the two analyses recently made by myself, as well as the corresponding ones of Röhrig. A few other analyses of similar rocks are inserted for comparison, and will be referred to subsequently.

It will be seen that Röhrig's analysis of the normal kulaite (II) agrees very well with mine (I) in all respects except in Fe_2O_3 and K_2O, which are respectively about 2 per cent. higher and lower. On the other hand, his of the leucite-kulaite (IV) resembles mine (III) only in MgO, CaO, and Al_2O_3, the TiO_2 present being weighed by him with the Al_2O_3. The other constituents differ rather widely.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
SiO_2	48.35	48.24	49.90	47.74	42.68	41.01	44.77	47.83	48.24	46.48	49.69
Al_2O_3	19.94	20.64	19.89	20.95	9.42	11.58	17.82	16.09	17.43	16.16	18.06
Fe_2O_3	2.48	4.63	2.55	3.29	11.55	12.54	5.05	4.32	7.22	6.17	2.64
FeO.....	5.25	5.55	4.78	6.32	7.23	7.60	6.95	3.62	1.17	6.09	6.19
MgO.....	5.15	5.02	5.05	5.16	10.09	8.67	8.22	5.53	3.99	4.02	5.73
CaO.....	7.98	7.94	7.21	7.56	13.15	12.20	10.36	10.68	6.09	7.35	8.24
Na_2O.....	5.47	5.08	5.60	7.12	2.71	2.57	2.13	4.46	4.28	5.85	2.99
K_2O.....	3.99	1.88	3.74	1.21	1.16	1.45	0.92	4.05	4.62	3.08	3.90
H_2O 110°+.	0.22	0.02	0.19	0.04	1.06	1.87	2.64	0.24	2.78	4.27	0.91
H_2O 110°−.	0.16		0.13					0.05			
CO_2.....	....	....	....	....	....	....	....	....	....	0.45	....
TiO_2	0.12	....	0.93	....	0.51	0.48	0.53	2.27	2.89	0.99	0.85
P_2O_5	0.84	0.97	trace	0.13	1.29	0.75	0.72	0.47	1.33	....	0.81
Cl.....	....	....	....	....	....	....	....	....	....	....	0.13
MnO	trace	....	trace	....	....	....	trace	0.38	trace	....	0.13
	99.95	99.97	99.97	99.52	100.85	100.72	100.11	99.56	100.47	100.91	100.27

I. Kulaite. Well digging. Kula. H. S. Washington anal.

II. Kulaite. Well digging. Kula. A. Röhrig anal. Am. Jour. Sci., Vol. XLVII, p. 122, 1894.

III. Leucite-kulaite. Near Gediz-chai, Kula. Washington anal.

IV. Leucite-kulaite. Near Gedis-chai, Kula. A. Röhrig anal. Loc. cit.

V. Hornblende-basalt. Todtenkopfchen, Rhone. Sommerlad anal. Neu. Jahr Beil, Band II, p. 155, 1883.

VI. Hornblende-basalt. Sparbrod, Rhone. Sommerlad anal. Loc. cit.

VII. Hornblende-basalt. Kosk Creek, California. Eakins anal. Diller. Amer. Geol., Vol. XIX, p. 255, 1897.

VIII. Leucite-tephrite. Falkenberg, near Tetschen, Bohemia. R. Pfohl anal. Hibsch. Min. Pet. Mitth. Vol. XIV, p. 105, 1894.

IX. Leucite-nepheline-tephrite. Niedermendig, Laacher See. R. Mitcherlich anal. Zeit. deutsch. geol. Ges., Vol. XV, p. 374, 1863.

X. Monchiquite. Cabo Frio, Brazil. M. Hunter anal. Hunter and Rosenbusch. Min. Pet. Mitth., Vol. XI, p. 454, 1890.

XI. "Basalt." Table Mountain, Denver, Colorado. Eakins anal. Cross. Mon., XXVII U. S. Geol. Surv., p. 308, 1896.

As the original specimens were small, these differences cannot be ascribed to differences of composition in different parts of the mass, but are more probably due to the different analytical methods used. This applies especially to the alkalis, in the determination of which the usual German method of treatment of the rock with HF and H_2SO_4, and subsequent separation of Al, Fe, Mg, and Ca, instead of the much more expeditious and accurate method of J. Lawrence Smith, tends to erroneous and discrepant results largely through contamination with alkalis derived from the glass vessels and reagents employed.

Having thus obtained an insight into the chemical and mineralogical composition of these rocks, it will be well to determine their place in the present scheme of classification.

In the first place, the very close correspondence of both my analyses, except in the minor constituents TiO_2 and P_2O_5, show that, in any scheme based on this character alone, they are to be classed together. Indeed, this is true of all the rocks of the Kula region examined by me, as shown by the analyses of Röhrig given in the original paper.

From a purely chemical standpoint it is abundantly evident that they are not to be referred to the basalts as this name is at present understood, since the alkalis are far too high for this group of rocks. The alumina is also too high, at least in comparison with the basalt analyses in which this constituent has been determined with proper care. Nor are they to be put with the subgroup of hornblende-basalts, as is shown by comparison with some typical analyses of these given in V, VI, and VII. The Kula rocks differ from these in having higher SiO_2, Al_2O_3 and alkalis, and lower iron oxides, MgO and CaO. In other words, they are more properly leucocratic, while the hornblende-basalts are melanocratic. At the same time the hornblende-basalt from Kosk Creek (VII), described by Diller, occupies a rather intermediate position between the Kula rocks and the typical hornblende-basalts of the Rhone and other regions.

The closest analogues of the Kula rocks are to be found among the nepheline-tephrites and nepheline-basanites. It is

true that many of these are markedly lower in SiO_2, Al_2O_3 and Na_2O, but at the same time analyses of these are to be found which closely resemble mine of the Kula rocks, as those of the nepheline-tephrite from the Falkenberg, near Tetschen, Bohemia, described by Hibsch (VIII), and the leucite-nepheline-tephrite of Niedermendig (IX).

They also resemble closely the monchiquites, as shown by a typical analysis of one of these (X), the main difference being in the higher content of H_2O in the monchiquites, consequent on their containing analcite in place of nepheline.[1]

Rocks which chemically closely resemble these are certain "basalts" from Colorado, described by Cross, an analysis of one of which is given in XI. These carry considerable orthoclase, but no nepheline, and with biotite instead of hornblende.

Turning to the mineralogical composition, it must be noted that most of the Kula rocks present a peculiarity which adds somewhat to the difficulty of classification. They have been spoken of as containing hornblende as an essential constituent. This is strictly true only of the more glassy varieties, in which basaltic hornblende is fresh and unaltered. In the others — including those analyzed — this mineral has been partially or entirely altered to hypersthene, diopside and magnetite, so that, speaking with strict accuracy as to their present composition the majority of them cannot be said to contain any hornblende at all.

This naturally raises the difficult question, whether the original hornblende should be recognized as a component. Of its initial presence, and the derivation of the hypersthenic and diopside-magnetite "mixed crystals" or pseudomorphs from it there can be absolutely no doubt, from the evidence of the shape of the pseudomorphs, the transitions to unaltered hornblende, and other facts observed here and elsewhere.

The case is strictly comparable with the occurrence of so-called "pseudo-leucites," mixtures of orthoclase and nepheline or muscovite, pseudomorphous after original leucite. As

[1] Cf. L. V. PIRSSON: JOUR. GEOL., Vol. IV, p. 679, 1896.

rocks containing these are called "leucite-syenite," "leucite-eleolite-syenite" and "leucite-phonolite" by Rosenbusch and Zirkel, it would seem to be justifiable, at least for the present, to speak of the Kula rocks as hornblende-bearing.

The analyses I and III calculate out very sharply as shown in the table below, with results worth commenting on. In the

	I a	III a[1]
Anorthite	17.9	17.9
Albite	8.4	23.6
Orthoclase	23.4	..
Leucite	..	17.4
Nepheline	20.4	12.8
Diopside	12.8	13.8
Olivine	10.7	9.5
Magnetite	3.7	3.7
Apatite	1.8	..
Water, etc.	0.8	1.3
	99.9	100.0

first place this calculation confirms the observation that nephe line is present, as there is too much Na_2O or too little SiO_2 to satisfy each other on any other basis.

It is also of interest to note that, although these rocks are so basic in composition, and so basaltic in general habit and appearance, yet the feldspars and feldspathoids constitute over 70 per cent. of the mass, and that they consequently are leucocratic, to use the distinction into two groups recently given by Brögger.[2] So little is known of the rocks of Asia Minor that as yet no melanocratic complements of these are positively known, though it is to be expected that they will be discovered some time in this petrographic province.

It will be noticed that in I the plagioclase is a bytownite of the composition $Ab\ An_4$, while in II it is an andesine, approximately $Ab_3\ An_2$. It is certainly remarkable that in the one

[1] Inasmuch as diopside, hornblende, hypersthene and olivine are present together in III, it is impossible to calculate the exact relative amounts of each, and the analysis has, therefore, been calculated on the assumption that only diopside and olivine are present. The error involved will not be large, as the hornblende tends to alter to a mixture of diopside and magnetite.

[2] BRÖGGER: Erupt. gest. d. Kristianiageb, III, p. 263, 1898.

rock orthoclase is associated with the lower SiO_2, as well as with a bytownite, while in the other leucite occurs with higher SiO_2 and lower K_2O, and with the plagioclase an andesine. In the latter also the albite molecule is higher and nepheline correspondingly lower, while the other constituents (except apatite) remain the same.

This is peculiar, but there seems to be no doubt of the facts, and the difference is possibly to be connected with differences in the conditions of solidification. The specimen of I came from a depth of thirty-five meters in a lava flow, possibly of Kula Devit, but more probably of an earlier volcano, while the leucite-kulaite was from the surface of a late flow of Kula Devit.

There would thus have been certain, even if slight, differences in pressure and rate of cooling, which might account for the difference in mineralogical composition. It has already been pointed out elsewhere[1] that these intermediate latitic magmas seem to be in a nicely balanced state of chemical equilibrium which only need very slight differences in conditions of solidification to result in quite diverse mineralogical aggregates. The facts here are also in accordance with the general observation that leucite is essentially a mineral of the effusive rocks, while orthoclase occurs in either intrusive or effusive masses, this tendency toward the formation of leucite in flows in contradistinction to the formation of orthoclase in domal eruptions being especially well seen along the main line of Italian volcanoes.[2]

We have already seen that the analyses correspond most nearly with those of the tephrites. Accepting, however, the general definition of a tephrite as an effusive rock composed essentially of plagioclase and nepheline or leucite, with pyroxene or other ferromagnesian components, it is very clear that the rock represented by analysis I, which contains 23 per cent. of orthoclase, cannot properly be put in this group. Indeed,

[1] H. S. WASHINGTON: JOUR. GEOL, Vol. V, p. 376, 1897.
F. L. RANSOME: Amer. Jour. Sci., Vol. V, p. 370, 1898.

[2] Cf. JOUR. GEOL., Vol. V, p. 376, 1897.

the calculated mineral composition, yielding 23.4 per cent. of orthoclase and 26.3 of plagioclase, is fully corroborative of the position to which Rosenbusch assigns this rock, among the latites or trachydolerites.

It would seem, then, advisable, as well as justifiable, to reserve the name "kulaite" to denote a basic rock of the series of latites (Rosenbusch's trachydolerites), in which orthoclase and lime-soda feldspar are present in about equal amounts, together making up half the rock, with nepheline to the extent of from 12.5 to 25 per cent. The ferromagnesian constituent is typically hornblende or pseudo-hornblende, and diopside and olivine are also present. These rocks, though low in silica, are essentially leucocratic in character.

The case of the "leucite-kulaites" is rather different. On the basis of chemical composition and genetic association they would naturally be classed with the kulaites, as varieties of these in which leucite replaces orthoclase. At the same time, composed as they are of plagioclase, nepheline and leucite, with ferromagnesian minerals, they are perfectly covered by the tephrites, and in the present schemes must be called leucite-nepheline tephrite.

I have gone at some length into the question of the position and names of these rocks, not because the matter is of any great importance in itself, but because they serve very well to exemplify the difficulties and complexities of our present methods of classification. It is the old story of magmas of identical chemical compositions solidifying as different mineral aggregates. With the rapid increase in our knowledge of rocks, and especially through more numerous analyses and their more careful execution, examples of this are becoming of quite frequent occurrence in petrographical literature. Most cases, as those of venanzite and madupite, the minette or selagite of Monte Catini and wyomingite, and many more, are of rocks from widely distant parts of the globe.

Here, however, there are found at one small center recent flows which must be referred to the distinct groups of basic

latites, leucite-tephrites and, to include the tachylitic varieties described in the original papers, hornblende-limburgites. These rocks which, according to the principles of classification at present in vogue, we must place in such diverse and distant parts of our scheme, are all products of one center of eruption, parts of the same undifferentiated magma, identical in chemical, and in many points of mineralogical, composition. A rational or natural scheme of classification should express their evident close relationship, but on account of somewhat diverse mineralogical composition, due to such extraneous and accidental causes as conditions of cooling and the like, their mutual affinities are to a large extent masked by the diverse names which must be given them.

We are brought face to face with the question, whether we should hold to the present system, based on structure and (largely qualitative) mineral composition; or whether we should strive to base our classification primarily on the most fundamental character of igneous rocks—their chemical composition, the quantitative mineral composition being a function and an exponent of this.

The choice of the latter would certainly seem to be justified on sound theoretical grounds, and has been advocated by Pirsson,[1] Iddings,[2] Brögger,[3] Loewinson-Lessing,[4] and others. It is, of course, also well known that Brögger holds that genetic relationships should find expression in classification; in other words, that the system of classification should be not a Linnean but a natural one. But discussion of this and kindred topics would carry us far beyond the limits of this paper.

That any change will present difficulties of a practical as well as of a theoretical nature is obvious. The aid of chemical analysis, as well as of the microscope, must be invoked much more often than in the past, though with increasing knowledge

[1] PIRSSON, Amer. Jour. Sci., Vol. L, p. 478, 1895.

[2] IDDINGS, JOUR. GEOL., Vol. VI, p. 103, 1898.

[3] BRÖGGER, Amer. Jour. Sci., Vol. IX, p. 458, 1900.

[4] LOEWINSON-LESSING, Compt. Rend., VII, Cong. Geol. Int., 1897, pp. 193–464.

this would be less vital in many cases than may be thought by some. Cases of uncertainty as to the position and relationships of a particular rock will occur, but presumably less frequently than under the present system. These and other difficulties will have to be met and overcome. But, as Iddings, Brögger, and others have urged, the time is at hand for a revision and change of our whole system of classification and subsequently of nomenclature, and it is well to remember the general truth of the saying, "*C'est le premier pas qui coûte.*"

HENRY S. WASHINGTON.

SUCCESSION AND RELATION OF LAVAS IN THE GREAT BASIN REGION[1]

RICHTHOFEN'S STUDIES

THE Great Basin was early recognized as showing a variety of Tertiary lavas which are identical over large areas, and erupted in somewhat the same succession. The first deductive studies from these facts were made by the Baron von Richthofen,[2] and were published in 1867. Partly as a result of observations in the rocks of the Great Basin and of California, and partly from studies in the volcanic regions of Europe, Richthofen arrived at what he considered to be the natural law for the sequence of massive eruptions, applicable to all centers of volcanic activity. According to him the order of succession was:

1. Propylite.
2. Andesite.
3. Trachyte.
4. Rhyolite.
5. Basalt.

This law of succession was accepted without much question for a long time by many European and American geologists.

THEORIES OF THE ORIGIN OF IGNEOUS ROCK DIFFERENCES PREVIOUS TO RICHTHOFEN[3]

By way of summarizing briefly the difference between Richthofen's theories and those of his predecessors, it may be remarked that Bunsen, who was one of the first to speculate concerning rock differences, after visiting Iceland and studying the volcanic phenomena, formed the hypothesis of two distinct magmas or bodies of lavas, one acid, and the other basic; the normal "trachytic" and the normal "pyroxenic" magmas,

[1] Published by permission of the Director of the United States Geological Survey.

[2] "Natural System of Volcanic Rocks," Mem. California Acad. Sci., Vol. I, p. 36.

[3] See Monograph XX, U. S. Geol. Surv., p. 273.

as he called them. He regarded all lavas between these extreme types as mixtures of the two in varying proportions. It will be noted that Bunsen's explanation[1] was essentially a theory of mixing rather than of differentiation.

Durocher[2] accepted Bunsen's idea of the existence of an acid and a basic magma, and admitted the possibility of a mingling of the two in certain cases to produce intermediate types, but did not follow this idea to the extent of Bunsen. Durocher proposed the hypothesis, which was not substantiated by much study of volcanic action in the field, that certain lavas may be produced by segregation, or differentiation, *i. e.*, by the breaking up of a magma into several different parts, as a result of chemical activity. Durocher's ideas of the origin of igneous rocks, therefore, include the idea of segregation, or differentiation, together with that of mixing.

Roth[3] later also held that a magma may segregate during crystallization into lavas of different mineralogical composition, although his ideas of the processes of differentiation were not specifically identical with those of Durocher, who had considered these processes analogous with those by which metals are segregated in metallurgical operations.

Von Waltershausen,[4] after studying the lavas of Sicily and Iceland, came to the conclusion that lavas were derived from a zone of molten material between the earth's crust and its solid interior, and that the material arranged itself according to the laws of gravitation, so that the most siliceous lava, which is also the lightest, was nearest the surface; the most basic at the bottom, and the intermediate lavas in the zones between. His own observations in the field seemed to point out that the lavas were

[1] Ueber die Processe der vulkanischen Gesteinsbildung Islands, Poggendorf's Annalen, 1851, Band 83, pp. 197–272.

[2] Essai de Pétrologie comparée, Ann. d. Mines, Paris, 5th series, 1857, Tome XI, pp. 217–259.

[3] Tabellarische Uebersicht der Geistens-Analysen, mit kritischen Erläuterungen, Berlin, 1861.

[4] Ueber die vulkanischen Gesteine in Sicilien und Island und ihre submarine Umbildung, Göttingen, 1853.

thrown out according to their supposed superposition, the order being, therefore, regularly from acid to basic lavas.

KING'S WORK AND ITS LATER MODIFICATIONS

The first careful work on the lavas of the Great Basin was done during the 40th Parallel Survey, the field-work of which was done chiefly by Messrs. Hague and Emmons, while the petrographic work was by Professor Zirkel, and the general results and deductions were made by the director, Mr. Clarence King.[1] Mr. King accepted in general the law of succession of volcanic rocks, as laid down by Richthofen, but subdivided the lavas of each member of the succession, and united the fourth and fifth members — the rhyolite and basalt[2] — under a general term, "Neolite." The natural order, as interpreted by King, was as follows:

Order	Subdivision
1. Propylite	*a*. Hornblende propylite.
	b. Quartz propylite.
	c. Augite propylite.
2. Andesite	*a*. Hornblende andesite.
	b. Quartz andesite (Dacite).
	c. Augite trachyte.
3. Trachyte	*a*. Hornblende-plagioclase trachyte.
	b. Sanidine trachyte (quartziferous).
	c. Augite trachyte.
4. Neolite	*a*. Rhyolite.
	b. Basalt.

As regards the laws maintained by Richthofen and King for the Great Basin, it is necessary to observe first of all that the first member — propylite — was proved by Mr. George F. Becker[3] to be simply a decomposed phase of the andesite in the Washoe district, instead of a separate rock, as supposed by Richthofen

[1] Geological Explorations of the 40th Parallel, Vol. I, p. 545 et seq.

[2] This colligation of rhyolite and basalt was made by King on the basis of their close association in the field. His explanations of this fact, however, were essentially different from later ones, now generally accepted, and first advanced by Mr. Hague, Mon. XX, U. S. Geol. Surv.

[3] Geology of the Comstock Lode, Washoe District, Mon. III, U. S. Geol. Surv., p. 88.

This conclusion was corroborated by subsequent investigators in different parts of the world, so that the term has passed out of use. It has also been proved by Mr. Becker's studies, and later by those of Messrs. Hague and Iddings,[1] that the trachytes of Richthofen and of the 40th Parallel Survey, as determined by Zirkel, are mainly andesites — in part hornblende-mica andesite, and in part hypersthene-augite andesite (the latter rock corresponding more nearly to the augite-trachyte of Zirkel), while a smaller proportion are dacites, and some are probably rhyolites. It has been determined by these investigators that trachyte is conspicuously absent in the province of the Great Basin. The reason for Zirkel's false classification was the lack of means at that time to determine the feldspars, so that the plagioclases were determined as sanidine, since they showed little or no striation.

SUCCESSION OF LAVAS PREVIOUSLY DESCRIBED IN THE GREAT BASIN AND VICINITY

Eureka district.— In the course of a careful study of the volcanic rocks of the Eureka district in Nevada, Mr. Hague[2] arrived at the following succession of lavas at this center of volcanic activity:

1. Hornblende andesite.
2. Hornblende-mica andesite.
3. Dacite.
4. Rhyolite.
5. Pyroxene andesite.
6. Basalt.

Washoe district.— In the Comstock or Washoe district, at the southern end of the Virginia Range, Mr. Becker[3] found the following succession of igneous rocks:

1. Granite.
2. Diorite.
3. Quartz-porphyry.

[1] "Volcanic Rocks of the Great Basin," Amer. Jour. Sci., June 1884, p. 453. Geology of the Eureka District, Mont. XX, U. S. Geol. Surv., p. 230 et seq.

[2] Mon. XX, U. S. Geol. Surv., p. 290. [3] Mon. III, U. S. Geol. Surv., p. 380.

4. Earlier diabase.
5. Later diabase.
6. Earlier hornblende andesite.
7. Augite andesite.
8. Later hornblende andesite.
9. Basalt

Messrs. Hague and Iddings,[1] after a careful microscopic study of the collections made by Mr. Becker in the Comstock region, arrived at somewhat different conclusions, although agreeing with Mr. Becker as to the identity of propylite with andesite. They concluded that the granular diorite and diabase, and the augite andesite, were variations of the same body, the granular rocks representing textural differences brought on by slowly cooling in the deeper parts of the extruded mass, while the finer-grained porphyritic rocks represented the periphery of the same. To substantiate their conclusion they show the existence of all possible gradations between the extreme types They also conclude that the porphyritic diorite is identical with the hornblende andesite, and the mica diorite with the later hornblende andesite, the difference in each case being due to variations of texture. The quartz-porphyry of Mr. Becker they regard as partly dacite, and partly rhyolite; while the later diabase, or "black dike," they regard as identical with the effusive basalt. They find, also, that the pyroxene and hornblende andesites are difficult to separate, but that these are cut through by hornblende andesites, dacites, rhyolites, and basalts. The succession of lavas in this district is, according to Mr. Hague:

1. Pyroxene-hornblende andesite (inner portions pyroxene-hornblende diorite porphyry, and pyroxene-hornblende diorite).
   Period of volcanic rest and denudation.
2. Hornblende-mica andesite.
3. Dacite.
4. Rhyolite.
5. Pyroxene andesite.[2]
6. Basalt.

[1] "On the Development of Crystallization in the Igneous Rocks of Washoe," Bull. 17, U. S. Geol. Surv.

[2] See Mon. XX, U. S. Geol. Surv., p. 281. Compare the succession in the adjacent Pine Nut Range, p. 628.

The hornblende andesite of Eureka is correlated with the hornblende-mica andesite of Washoe, while the pyroxene-hornblende andesite of Washoe is supposed to belong to an earlier period, not represented at Eureka; otherwise the succession of lavas at the two centers of eruption is considered to be similar and the different extrusions in general contemporaneous.

Sierra Nevada.— Mr. H. W. Turner[1] published in 1895 a résumé of the age and succession of igneous rocks in the Sierra Nevada. According to him the succession of the Tertiary volcanics in this region is as follows:

1.	Acid - - - -	Rhyolite — massive and fragmental.
2.	Basic - - -	Older basalt — always (?) massive.
3.	Intermediate - -	Hornblende-pyroxene andesite — chiefly tuff and breccia.
4.	Intermediate to acid -	Fine-grained pyroxene andesites — massive
5.	Basic - - - -	Doleritic basalts — massive.
6.	Basic - - -	Other basalts — massive.

In 1898 Mr. F. L. Ransome[2] published a critical study of a portion of the western slope of the Sierra Nevada, in the Sonora and Big Trees region — a locality, it may be noted, much nearer to the Washoe district than the Washoe is to Eureka. Mr. Ransome succeeded in classifying more accurately than had hitherto been done some of the intermediate lavas, determining rocks that had previously been classified variously as basalts, trachytes and andesites as belonging to the monzonitic family, intermediate between the granitic and dioritic families. For the volcanic variety of monzonite he proposed the term "latite." The succession of the Tertiary lavas in the region studied by Mr. Ransome is as follows:

1. Biotite rhyolite.
   Rhyolite tuffs.
2. Olivine-basalt.
3. Hornblende-pyroxene andesite brecca.

[1] Jour. Geol., Vol. III, No. 4, May–June 1895.

[2] Bull. 89, U. S. Geol. Surv. Also Amer. Jour. Sci., May 1898, 4th series, Vol. V, p. 355.

4. Latite { Augite-biotite hornblende latite. / Biotite-augite latite.
5. Hornblende-pyroxene andesite breccia.
6. Olivine-basalt.

Tintic district.— Passing from the Sierra Nevada and the western border of the Great Basin (from the Sonora region and the Washoe district) eastward past Eureka, we will next cite the record of Tertiary vulcanism in the Tintic Range, which lies south of Salt Lake and southwest of Utah Lake, and is approximately the same distance from Eureka as Eureka is from Washoe. This region has been studied by Messrs. Tower and Smith.[1] The succession of lavas is as follows:

1. Biotite rhyolite.
2. Pyroxene-hornblende-biotite andesite — tuffs and breccias.
3. Pyroxene-hornblende andesite (latite).
4. Olivine-basalt.

The rhyolitic flows of the first member of the succession given above are known to be continuous and contemporaneous with dikes of rhyolite which, on account of their somewhat different habit, were given the name of *quartz-porphyry* in the text. This intrusive rhyolite appears to be susceptible of correlation with the rhyolite or "quartz-porphyry," described by the writer,[2] from the northern end of the Oquirrh Range, which lies south of the Tintic district (Eagle Hill porphyry). The rhyolite in the Tintic district is known to be later than Upper Eocene.

The pyroxene-hornblende andesites (or latites) described by Messrs. Tower and Smith are regarded by them as belonging to the same general body as certain large masses of granular monzonite with which they are connected by transitional phases; the monzonite representing portions of the magma which have consolidated as intrusive masses under conditions favoring better crystallization than those under which the extrusive sheets of pyroxene andesite (or latite) have consolidated. These

[1] "Geology and Mining Industry of the Tintic District, Utah," Nineteenth Annual Rept. U. S. Geol. Surv., Part III, Economic Geol., p. 632.

[2] J. E. SPURR, "Economic Geology of the Mercur Mining District," Sixteenth Ann. Rept., Part II, p. 377.

transitions from typical fine-grained extrusives to porphyritic and to coarse granular intrusive rocks are highly interesting in themselves and by comparison with the similar phenomena which Messrs. Hague and Iddings[1] have found in the andesite and basalts of the Washoe district. The present writer has also found similar transitions, to be described elsewhere.

SUCCESSION OF LAVAS AT OTHER POINTS IN THE GREAT BASINS

During the past season's field work the writer has observed the succession of lavas at many different points in the Great Basin. From the nature of the work the time for study was in each case very restricted, so that the records given below are sometimes very likely incomplete.

Pine Nut Range.—The Pine Nut Range is interesting on account of lying immediately south of the Virginia Range and the Washoe district, and because the lavas of this district are easily recognizable in it. The range was crossed at two points, one east from Dayton and one east from Genoa. The succession of lavas appears to be as follows:

1. Rhyolite (intimately connected and probably contemporaneous with granite of similar constitution).
   Rhyolite sands and conglomerates (formed during long period of erosion).
2. Hornblende-pyroxene-biotite andesite (in portions sufficiently removed from the surface the typical glassy or microcrystalline groundmass of the lava becomes coarser, leading to the formation of diorite porphyry and monzonite porphyry).
3. Hornblende-mica andesite.
   Period of denudation.
4. Rhyolite (Shoshone Lake period?).
5. Hornblende-pyroxene andesite, tuffs, and breccias (Shoshone Lake period).
6. Rhyolite.
7. Basalt (Pleistocene).

Of these extrusives the first appears to have been greatest in amount and the latter ones in general progressively less and less, in the order of their arrival.

[1] Bull. 17, U. S. Geol. Surv.

Sweetwater Range.—The Sweetwater Range may next be considered, since it lies south of the Pine Nut Range and shows very nearly the same rocks. It is separated from the Pine Nut Range only by the Walker River Valley, while at its southern end it connects with the Sierras, of which it may thus be considered a spur.

The observed succession of lavas in this range is as follows:

1. Rhyolite (closely connected and perhaps contemporaneous with granites of similar composition).
2. Hornblende-pyroxene andesite.

   Epoch of erosion and subsequent formation of Shoshone Lake.
3. Hornblende-pyroxene andesite, tuffs and breccias.
4. Hornblende-biotite latite.
5. Basalt.

Gabb's Valley Range.—In the lavas of Gabb's Valley and the Gabb's Valley Range, which lies just east of Walker Lake, the following succession was made out:

1. Biotite andesite.
2. Biotite rhyolite.
3. Hypersthene-hornblende aleutite.[1]
4. Augite basalt.

A granular rock, which had every appearance of being effusive, was also found in Gabb's Valley, and on examination proved to be a hornblende-biotite quartz-monzonite. This, however, is not included in the list, since its exact position is uncertain. It is very likely earlier than all the others and is perhaps contemporaneous with the biotite-hornblende quartz-monzonite, which forms the oldest rock in the Walker River Range, being more ancient than the granite.

Silver Peak Mountains.—Mr. H. W. Turner, who has studied the volcanic record in the Silver Peak district, has kindly supplied the writer with the preliminary statement that in general the succession of lavas here is as follows:

1. Rhyolite.
2. Andesite.
3. Basalt.

[1] See American Geologist, April 1900, p. 230.

Ralston Desert.— According to observations made by the writer, the succession of lavas in the Ralston Desert is as follows:

1. Rhyolite and tordrillite[1] (earlier).
2. Rhyolites, often glassy (late Pliocene).
3. Olivine-basalt (Pleistocene).

Practically the same succession is seen in the Kawich Range and in the Reveille Range.

Lake Mono Basin.[2]— In the basin of Lake Mono, according to Professor Russell, we have extensive Pleistocene volcanic activity, the lavas being basalt, hypersthene andesite verging on basalt, and rhyolite. Older than these is a hornblende andesite. The succession in this basin is, then:

1. Hornblende andesite.
2. Basalt, hypersthene andesite verging on basalt, rhyolite.

The relative age of the lavas under 2 was not determined, but they are all regarded as Pleistocene.

Toyabe Range.— In the southern end of the Toyabe Range the known succession of Tertiary lavas is as follows:

1. Biotite rhyolite (closely associated and perhaps contemporaneous with intrusive biotite granite).
2. Augite basalt (Pleistocene).

Schell Creek Range.— In the Schell Creek Range, near Schellbourne, we have the following succession of lavas:

1. Biotite rhyolite (flows often glassy).
2. Pyroxene aleutite (probably late Pliocene).

Egan Range.— In the Egan Range the following lavas were found:

1. Dacite-andesite.
2. Basalt.

Meadow Valley Canyon.— In the Meadow Valley Canyon (southward from Pioche) we have one of the best exposures of Tertiary lavas and their associated sediments which has yet been

[1] See Classification of Igneous Rocks according to Composition, J. E. SPURR, Am. Geol., April 1900, p. 230.

[2] Quaternary History of Mono Valley, California; Eighth Ann. Rept. U. S. Geol. Surv., Part I, p. 374, 379, etc.

found in Nevada. The completeness of the section enables one to see how complicated the history of Tertiary vulcanism and sedimentation is, but the following is the general succession:

1. Biotite rhyolite.
   Rhyolite tuffs and sands.
2. Pyroxene andesite, tuffs and breccias.
   Biotite-hornblende quartz-latite (basic).
   Biotite-hornblende dacite.
   Biotite-hornblende rhyolite, and tordrillite (heavy flows).
   Thin-bedded rhyolite (Pliocene).
3. Pyroxene olivine-basalt.
   (Pleistocene.)
   Rhyolite-tordrillite.

Funeral Range.—The volcanic activity of the Funeral Range has not been very well observed, but the following is part at least of the succession:

1. Biotite andesite (Eocene or Miocene).
2. Olivine-basalt.

Panamint Range.—In the Panamint Range the following succession of lavas has been observed:

1. Feldspathic lavas of medium acidity; species undetermined.
   Rhyolite.
2. Andesite (late Eocene or Miocene).
3. Pyroxene aleutites and basalts, often olivine-bearing (late Pliocene or Pleistocene).

Randsburg region.—In the mountains in the vicinity of the mining camp of Randsburg, in southern California, the writer observed the following succession:

1. Biotite rhyolite (early Eocene?).
   Rhyolitic tuffs and sands.
2. Hornblende-pyroxene-biotite aleutite.
3. Pyroxene basalt
   (Pleistocene.)
   Pyroxene olivine-diabase porphyry (dike).

Coso Range.—According to Mr. Fairbanks,[1] the following is the succession of lavas in this range, roughly stated:

1. Rhyolites and andesites.
2. Basalts.

[1] Am. Geol., Vol. XVI, February 1896, p. 73.

Daggett or Calico region.—Southward, in the middle of the Mojave Desert, at Daggett, or Calico (which is on the Mojave River and also on the Santa Fé Railway), great masses of rhyolite have been described,[1] underlying the borax-bearing lake beds which are probably, in part at least, Upper Eocene. These rhyolites are plainly the same as those in the Coso Range and in the Randsburg region.

SUCCESSION OF LAVAS IN THE GREAT BASIN REGION IN GENERAL

In the field it is evident that the same lavas occur in many different localities throughout the Great Basin region, in much the same relative quantity, having nearly the same mineralogical composition, and giving evidence of about the same relative age. Moreover, where two or more of these lavas are found close together, their order of succession is found to be in general nearly the same, although at any given place certain members of the series may be lacking. In no single locality has the complete succession, as indicated by the correlation of all the different sections, been observed; but in order to find it we may fill gaps in one place from the observations in another. In correlating similar lavas erupted at different points, we must consider not only the succession but the relative age of each, so far as this is known. The evidence of this age will be briefly outlined later on; it is with this in mind, however, that the following table has been made. Many of the correlations are only provisional, and will probably require adjustment and rearrangement as the result of future investigation; but it is believed that the general deductions are correct.

By this correlation we see that the succession of lavas seems to have been roughly uniform over the whole region, although minor variations have been numerous at many points. In general, it appears possible to divide the lavas into five groups, in the order of their eruption, as follows:

1. Acid (type, biotite rhyolite).
2. Siliceous intermediate (medium andesites).

[1] W. H. STORMS: Eleventh Rept. State Mineralogist California, p. 347. Sacramento, 1893.

3. Acid (rhyolites with composition like 1) with occasional connected basalts.
4. Basic intermediate (more basic andesites and aleutites).
5. Basic (basic basalts), frequently with closely connected rhyolites.

CORRELATION OF LAVA GROUPS IN POINT OF AGE

The absolute age of the different Tertiary lavas is not easy to find out, although in many special cases it may be done with a fair degree of accuracy. The most recent eruptions are naturally the most easy of determination, while those more remote are more obscure.

1. *Acid.*—In the Pine Nut and Sweetwater ranges the definite age of the older rhyolites is uncertain, but they are separated from the great bodies of massive hornblende-pyroxene-biotite andesite, which itself antedates the Pliocene Shoshone Lake, by a long period of erosion. These rhyolites are also affected by a sheeting which is not found in the andesites, and which indicates crustal disturbance between the eruption of the two lavas.

The observations concerning the Pine Nut and Sweetwater ranges are in general true, also, for the Reveille, Quinn Canyon, and Grant ranges.

In Meadow Valley Canyon the basal rhyolite, with its overlying tuffs, is folded and separated by a marked unconformity from the andesitic lavas and tuffs which succeed. The rhyolite tuffs are roughly estimated at 4000 feet thick, and mark a long period of Tertiary sedimentation, which intervened between the rhyolites and the andesites.

In the Silver Peak region rhyolites are interbedded in portions of the Tertiary lake sediments, which are probably late Eocene or early Miocene.[1]

In the Panamint Range, in the Randsburg district, and near Daggett in the Mojave Desert, lake beds which are probably in part at least Upper Eocene overlie the basal rhyolite.

In general, therefore, it may be said that the age of the rhyolite, which is the first member of the general succession,

[1] H. W. TURNER: The Esmeralda Formation. Am. Geol., Vol. XXX, March 1900, p. 168.

varies in different portions of the petrographic province from early to late Eocene. Strict contemporaneity is not to be expected, but only broad correspondence.

2. *Siliceous intermediate.*—In the region of the 40th Parallel Survey, Mr. King[1] considered that the beginning of Miocene time came between the main period of the hornblende andesites (No. 2 of the succession here outlined) and that of the augite andesites (No. 4 of this succession). Mr. King found his Miocene beds (sediments of the Pah-Ute Lake) largely made up of tuffs derived from what was at that time regarded as trachyte, and he therefore considered the trachytic period as Miocene. The trachytes of the 40th Parallel Survey have been shown to be mainly andesites, in part hornblende-mica andesites and in part pyroxene andesites.[2]

In the Virginia, Pine Nut and Sweetwater ranges, the hornblende-pyroxene-biotite andesites were erupted and eroded previous to the formation of the Shoshone Lake, to which they formed the shores. The Shoshone Lake probably existed in late Pliocene and earliest Pleistocene time; this puts back the age of these andesites to at least early Pliocene.

In the Silver Peak region andesites occur, together with abundant andesitic tuffs, in portions of the Esmeralda formation, which is probably late Eocene or early Miocene.

In the El Paso Range, according to Fairbanks, andesite occurs as interstratified sheets in the late sediments of the Upper Eocene.

Taken altogether, it may be said that the period of eruption of the medium-siliceous andesitic lavas was chiefly in the Miocene, although it probably ran back to the Upper Eocene. The periods of eruption No. 1 and No. 2 therefore overlap, and they are actually found close together in certain of the Upper Eocene lake sediments.

Acid.—Concerning the age of the third member of the succession there are somewhat better data. In the 40th Parallel

[1] Explorations of the 40th Parallel, Vol. I, p. 692.

[2] HAGUE and IDDINGS: Volcanic Rocks of the Great Basin. Am. Jour. Sci., 3d series, Vol. XXVII, January 1884, p. 456.

region Mr. King[1] notes that the rhyolites and rhyolite tuffs seem to be Pliocene. In the Eureka district Mr. Hague[2] came to the same conclusion as regards the rhyolite there.

In western Nevada rhyolities are found interbedded and therefore contemporaneous with the sediments of the late Pliocene Shoshone Lake in a number of localities, as, for example, on the borders of the Pine Nut Range. The same relation to the Shoshone Lake beds was noted on the western edge of the Ralston Desert.

In the mountains near Candelaria glassy rhyolite overlies the folded Upper Eocene or Lower Miocene of the Esmeralda formation. The folding which has affected these beds is the same as that which has upturned the Miocene further north, called by King the Truckee Miocene; so the disturbance must have been late Miocene or post-Miocene. The rhyolite in this case, therefore, is probably as young as the Pliocene.

In the Sierra Nevada Mr. Turner[3] referred the rhyolites to the Upper Miocene. According to Mr. Lindgren[4] the rhyolitic flows of the Sierra in the Truckee region began "toward the close of the Miocene."[5]

In general, therefore, the age of the second chief rhyolite eruption ranges from late Miocene well into the Pliocene.

Basic intermediate. — In the Sierra Nevada, according to Turner,[6] the pyroxene andesite is Pliocene.

[1] Explorations of the 40th Parallel, Vol. I, p. 694.

[2] Mon. U. S. Geol. Surv., Vol. XX, p. 232.

[3] Igneous Rocks of the Sierra Nevada, JOUR. GEOL., Vol. III, No. 4, May-June 1895, p. 406; Auriferous Gravels of the Sierra Nevada, Am. Geol., June 1895, p. 372.

[4] Truckee folio, U. S. Geol. Surv., p. 3.

[5] The writer was at first inclined to correlate the rhyolite of the Sierra Nevada with the earliest rhyolite shown in the general correlation table (No. 1 of the general succession); but a number of considerations, among others that of the comparatively slight age of the Sierra Nevada rocks, as given above, induced him to class them with later rhyolites (No. 3 of the general succession). In agreement with this conclusion are Hague's views (Mon. XX, U. S. Geol. Surv., pp. 261, 281.

[6] Age and succession of the Igneous Rocks of the Sierra Nevada, JOUR. GEOL. Vol. III, June 1895, p. 408.

In the Sweetwater Range, near Wellington, pyroxene andesite flows are found intercalated with the sediments of the great Pliocene Shoshone Lake.

In the Schell Creek, Antelope, and Snake ranges the pyroxene aleutite, which overlies glassy biotite rhyolite, has filled up valleys which are probably early Pliocene, and has suffered only slight erosion, resulting in the development of a narrow Pleistocene valley, since that time. It can hardly, therefore, be older than late Pliocene.

On the whole the main period of eruption of the basic intermediate lavas appears to have been during the Pliocene, and chiefly the late Pliocene. Most of the great andesitic breccias, indicating widely distributed explosive eruptions, seem to belong to this period.

5. *Basic.*—In the Eureka district it is suggested that the latest outbursts, which were of olivine-basalt, occurred in the Pleistocene.[1]

Near Steamboat Springs, which is just west of the southern end of the Virginia Range and in the immediate district of the Comstock lode, the writer observed that the olivine-basalt is probably early Pleistocene, since it has filled the valleys and covered the scarps eroded by the late Pliocene and early Pleistocene Shoshone Lake.

On the borders of the Pine Nut Range the basalt appeared after the Shoshone Lake had shrunk to the later Pleistocene Lake, and after the country exposed by this recession had been partly dissected into canyons. It is therefore plainly of Pleistocene age.

In the Ralston Desert and in the Reveille and Pancake ranges the basalt overlies the Pliocene sediments, supposed to belong to the Shoshone Lake period. In the Quinn Canyon and Grant ranges the basalt has been poured out into valleys which were probably formed in the late Pliocene period.

In most of the other localities where this lava has been found there is little doubt that the age is Pleistocene, although some of the eruptions may date back to the late Pliocene.

[1] Mon. U. S. Geol. Surv., Vol. XX, p. 232.

TABULATION

The relative age of the different members of the volcanic section, therefore, may be roughly outlined in the following table. It must be remembered that this is only approximate.

The age of the members of volcanic succession being determined, we can sometimes apply this determination in cases where the age of the lavas cannot be independently ascertained, and use them roughly as time markers.

Epochs of sedimentation	Standard time divisions	Epochs of vulcanism
	End of Cretaceous	
	Eocene	No. 1. Acid (type, biotite rhyolite)
Eocene-Miocene Lakes	Miocene	No. 2. Medium intermediate (type, hornblende-mica-pyroxene andesite)
		No. 3. Acid (type, biotite rhyolite)
	Pliocene	No. 4. Basic intermediate (types, pyroxene, andesite, etc.)
Shooshne Lake		
Lake Lahontan	Pleistocene	No. 5. Basic and acid (basalts and occasional rhyolites)
Walker Lake, etc.		

LAW OF SUCCESSION OF LAVAS

The most natural deduction from all these harmonious observations is that the Great Basin, southward into the Mojave Desert, together with a portion at least of the Sierra Nevada, constitutes a petrographic province; that is to say, it is underlain by a single body of molten magma, which has supplied, at different periods, lavas of similar composition to all the different parts of the overlying surface. The limits of this subcrustal basin, however, are not yet defined in any direction.

In studying the eruption of different lavas from this magma basin at different periods, it is instructive to inquire whether or not the succession follows any definite laws. Mr. Iddings[1] interpreted the usual law of succession in volcanic rocks as this: that a series begins with a rock of average composition, and passes through less siliceous and more siliceous ones to rocks extremely high in silica and others extremely low in silica—that is, the series commences with a mean and ends with extremes. This interpretation of Iddings was based on his work in the Yellowstone Park and vicinity, at Eureka, Washoe, and elsewhere. From studies of the eruptive rocks in the vicinity of Christiania Professor Brögger also thought to have determined a definite law of succession, by which the lavas progress from the most basic to the most acid varieties. Sir Archibald Geikie,[2] from a study of igneous rocks in Great Britain, has come to the same general conclusion as to the succession.

The section of Tertiary volcanics exposed at Eureka and Washoe, as given by Mr. Hague, begins with what is designated by the present writer No. 2 in the succession, and does not reach back to the basal biotite rhyolite. The general succession for the Great Basin, leaving out this basal rhyolite, appears, then, to be as follows:

2. Siliceous intermediate.
3. Acid (and basic).
4. Basic intermediate.
5. Basic (and acid).

[1] The origin of igneous rocks, Bull. Phil. Soc. Washington, Vol. XII, p. 145.

[2] Quar. Jour. Geol. Soc. Lond., 1892, Vol. XLVIII, p. 177.

Under No. 5 we find the very basic olivine-basalts and very siliceous rhyolites or tordrillites, erupted at the same period and evidently connected by the closest ties. This, for example, was observed to be the case in the Pleistocene volcanics of the Meadow Valley Canyon, and the same is true in the basin of Lake Mono, according to Russell.[1]

These closely allied ultra-basic and ultra-acid lavas are plainly complementary forms, and are proofs of differentiation as convincing as are the complementary segregations so familiar in single masses of intrusive or plutonic rocks.

Going a little further, if we write Nos. 3 and 4 of this last succession together and precede it by No. 2 (which we may divide into two members) we have the following grouping:

2. { Medium andesite.
   { Acid andesite and dacite.
3. { Acid rhyolite (with basalt).
4. { Medium basic andesite.
5. { Basalt.
   { Acid rhyolite.

We have here, therefore, a series (apparently conformable to Iddings' law) which begins with a rock of intermediate composition and progresses to extremes, as a result, probably, of differentiation.

But the first member in the order of succession as interpreted by the writer, viz., the basal rhyolite, is apparently out of place in this scheme. This rock has a composition essentially like the later rhyolite, but appears to have no immediate connection, mineralogically or chemically, with the andesites which form the base of the Eureka lavas. The andesites can hardly be derived from the rhyolites by any hypothetical differentiation, and even in that case the order seems in direct opposition to all of the hitherto propounded laws of succession.

It was first, therefore, the conclusion of the writer that the law deduced by Iddings would not hold good in the Great Basin, on

[1] Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Surv., Part I.

account of the basal rhyolite. From further study, however, the evidence of differentiation up to this point appears to be so good that he is inclined to accept it, and to consider the basal rhyolite as belonging to a different order of events.

This basal rhyolite is, in chemical and mineralogical composition, much like the latest rhyolite, No. 5, in the writer's order of succession. Like it, it often becomes extremely siliceous. From this circumstance, and from the apparent break in composition between the rhyolite No. 1 and the andesite No. 2, the writer conceived the idea that the two rhyolites are *recurrent* lavas — that is, that they represent a similar development in distinct but similar processes of differentiation. The development of lavas might then be interpreted as follows:

1. Acid rhyolite.

   Revolution and beginning of new epoch.

2. Medium to acid andesite and dacite.
3. Acid rhyolite (with basalt).
4. Medium basic andesite.
5. { Basic basalt. / Acid rhyolite.

In case this is the current grouping, it is probable that No. 1 represents the end product of a differentiation, and is similar to the rhyolite under No. 5; and that 2 to 5 inclusive represent an independent differentiation process.

The difficulty with the above arrangement is, first, the olivine-basalt, which we are obliged to couple with the rhyolite under No. 3. The existence and relations of this basalt in the Sierra Nevada seems to be well established. The second difficulty arises from the fact that the rhyolite No. 3 is of exactly the same acid type as the rhyolites under 1 and 5. From this fact the idea originates that rhyolite No. 3 may be also a recurrent lava, and that we have in the whole volcanic succession portions of three instead of two cycles of differentiation.

On testing this hypothesis we are struck with the fact that andesites 2 and 4 have identical phases, although the groups as a whole differ as stated in the above list. At Eureka the earlier and later andesites were held to be separate, the earlier ones

being more siliceous and not approaching the later ones more nearly than by 2.25 per cent. of silica.[1] At Washoe, however, the pyroxenic andesites, which precede the more siliceous andesites representing at Eureka the earlier group, become equally basic with the andesites of the second period. In other portions of the Great Basin also the andesites belonging to the first and second periods are often indistinguishable.

On studying the general succession, as partially set forth in the table of correlations, we find that the break between Nos. 3 and 4 in the succession is as abrupt as that between Nos. 1 and 2. On the other hand, between 2 and 3 there are many transitional phases, and also between 4 and 5.

We may represent the facts above noted, graphically, as follows:

1. Rhyolite.
2. Andesite.
3. Rhyolite (and basalt).
4. Andesite.
5. Basalt (and rhyolite).

The break between 3 and 4 was noted by Mr. Hague at Eureka.[2] He ascribed it to a change of magmas and argued that the first members of the succession at Eureka, beginning with hornblende andesite and ending with acid rhyolite, were derived from a magma distinct from that which produced the later members of the succession, beginning with pyroxene andesite and ending with basalt. In the first group Mr. Hague found, between the andesite and the rhyolite, gradual transitions which grew continually more siliceous; likewise in the second group he found gradual transitions between the pyroxene andesite and the basalt. This implies two distinct processes of differentiation, the first of which proceeded from intermediate to acid, while the second followed the opposite order, from intermediate to basic. Mr. Hague's interpretation of the development of lavas at Eureka may be graphically represented as follows:

[1] Monograph XX, U. S. Geol. Surv., p. 269.

[2] Monograph XX, U. S. Geol. Surv., pp. 254, 269, 270, 271.

Feldspathic Magma
- HORNBLENDE ANDESITE.
- ↓ Series growing gradually more siliceous.
- ACID RHYOLITE.

Pryoxenic Magma
- PYROXENE ANDESITE.
- ↓ Series growing gradually more basic.
- BASALT.

The *general* succession in the Great Basin region, as set forth in the table which we have made opposite this page, corresponds to Mr. Hague's conception (leaving out of the question the rhyolite No. 1, which is not exposed in the Eureka district). The relations of the lavas of the whole region, therefore, omitting the minor exceptions, might be represented as follows:

1. RHYOLITE.

Break.

2. ANDESITE.

↓ Gradual transitions.

3. RHYOLITE.

Break.

4. ANDESITE.

↓ Gradual transitions.

5. BASALT.

Nevertheless, the exceptions are frequent enough to demand recognition. Observations at several points outside of the Eureka district prove that basalt No. 5 has a closely associated rhyolite which is plainly complementary. Similarly, rhyolite No. 3 has in the Sierras an associated olivine-basalt, which is also probably complementary. Upon looking carefully, we find that there are complementary phases for the stages intermediate between the andesite No. 4 and the basalt No 5; and we become

	Eureka (Hague)	Washoe (Hague)	Sierra Nevada (Turner)	Sierra Nevada (Ransome)
1				
2	Hornblende andesite Hornblende mica andesite Dacite	Pyroxene-hornblende andesite (diorite and diabase) Hornblende-mica andesite (mica diorite, diorite porphyry) Dacite		
3	Rhyolite	Rhyolite	Rhyolite Basalt	Biotite rhyolite Olivine-basalt
4	Pyroxene andesite	Pyroxene andesite	Hornblende-pyroxene andesite, tuffs, and breccias Pyroxene andesite	Hornblende-pyroxene andesite breccia Latites: Augite-biotite-hornblende latite; Biotite-augite latite Hornblende-pyroxene andesite breccia
5	Basalt	Basalt (diabase)	Basalt	Olivine-basalt

PROVISIONAL CORRELATION OF TERTIARY LAVAS

	Sierra Nevada (Ransome)	Tinti[illegible] Range, Utah (Tower and [illegible])	Lake Mono (Russell)	Pine Nut Range	Sweetwate
				Biotite rhyolite (granite and alaskite)	Rhyolite (g
			Hornblende andesite	Hornblende-pyroxene-biotite andesite Hornblende-biotite andesite	Hornblend ene and
	Biotite rhyolite Olivine-basalt	Biotite rhyolite		Rhyolite	
ıe ıd	Hornblende-pyroxene andesite breccia Latites: Augite-biotite-hornblende latite; Biotite-augite latite Hornblende-pyroxene andesite breccia	Pyroxene-hornblende-biotite andesite, tuffs, and breccias Pyroxene-hornblende andesite (latite and monzonite)		Hornblende-pyroxene andesite, tuffs, and breccias	Hornblende ene andesi and brecci Hornblende latite (bre
	Olivine-basalt	Olivine basalt	Basalt Hypersthene andesite, verging on basalt Rhyolite	Rhyolite Basalt (hornblende basalt)	Basalt

etwater Range	Gabb's Valley	Ralston Desert	Schell Creek Range	Egan Range	Meadow Valley Canyon
lite (granite)		Rhyolite Tordrillite			Biotite rhyolite
blende-pyrox- e andesite	Biotite andesite			Dacite-andesite	
	Biotite rhyolite	Rhyolite	Biotite rhyolite		
blende-pyrox- andesite, tuffs, breccias blende biotite e (breccia)	Hypersthene- hornblende aleutite		Pyroxene aleutite		Pyroxene andesite breccia and tuff Biotite-hornblende quartz-latite Biotite-hornblende dacite Biotite-hornblende rhyolite
t	Augite basalt	Olivine-basalt		Basalt	Rhyolite Pyroxene olivine- basalt Rhyolite-tordrillite

Egan Range	Meadow Valley Canyon	Panamint Range	Randsburg Region
	Biotite rhyolite	Rhyolite	Biotite rhyolite
Dacite-andesite		Andesite	
	Pyroxene andesite breccia and tuff, Biotite-hornblende quartz-latite Biotite-hornblende dacite Biotite-hornblende rhyolite		Hornblende-pyroxene-biotite aleutite
Basalt	Rhyolite Pyroxene olivine-basalt Rhyolite-tordrillite	Pyroxene aleutite and basalt (often olivine-bearing)	Pyroxene basalt Pyroxene olivine-diabase porphyry (dike)

aware that these complementary forms constitute an acid-growing series, transitional between the andesite No. 4 and the rhyolite which is complementary with No. 5, and that this series appears to be in general contemporaneous with the basic-growing series between the andesite and the basalt. As an example of this acid-growing series consecutively observed, the section described in Meadow Valley Canyon is highly interesting; here we have a transition from pyroxene andesite through intermediate phases to Pleistocene rhyolite, which is complementary with Pleistocene basalt.

Between the andesite No. 2 and the olivine-basalt which is coupled with the rhyolite No. 3, we have not found such satisfactory transition phases, but this is perhaps due to the remoter age of this group of lavas.

We may, therefore, write the general succession and relation of the lavas of the Great Basin, as follows:

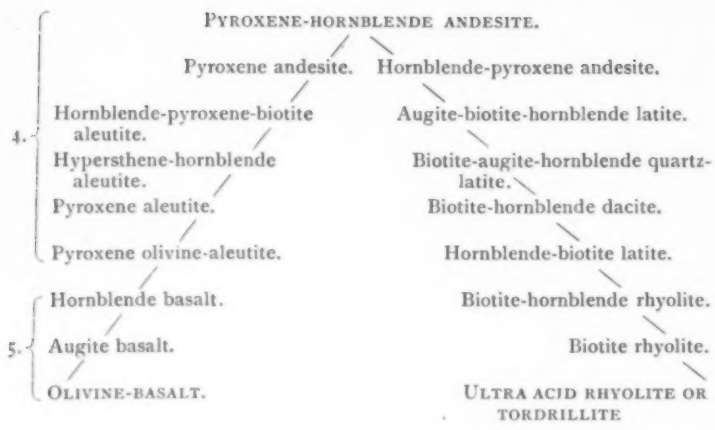
1. BIOTITE RHYOLITE AND TORDRILLITE.

2.
- PYROXENE-HORNBLENDE ANDESITE.
- Hornblende-pyroxene andesite.
- Hornblende andesite.
- Biotite andesite.
- Hornblende quartz-andesite.
- Dacite.
- Latite (?)[1]

Pyroxene andesite (?)

3. BIOTITE RHYOLITE. — OLIVINE-BASALT.

[1] Compare some of the analyses of the earlier andesites and dacites at Eureka (e. g., Mon. XX, U. S. Geol. Surv., p. 264, Nos. 4, 5, and 6), with those of latites given by DR. RANSOME (Bull. 89, U. S. Geol. Surv., p. 66).



It therefore appears that we have the representatives of two complete cycles of differentiation, and probably the end of a still earlier cycle. During the first completely recorded cycle (beginning with the earlier andesites) the more siliceous rocks were continually extravasated in preference to the more basic complements, so that the acid-growing series is far more prominent in the record than the basic-growing one. On the contrary, during the second or last complete cycle the more basic rocks were continually thrown out in preference to the more siliceous ones, making the basic-growing series more prominent. The laws which govern these apparently eccentric preferences of eruption are yet unknown.

I have looked in vain in the field for the earlier representatives of the first cycle of differentiation, to which No. 1 belongs. If they were erupted previous to the appearance of the rhyolite (No. 1) they have not yet been determined.[1]

[1] What may possibly be one of the members of the earlier differentiation cycle, older than the rhyolite, occurs in the Walker River Range. Here the granite and alaskite, which are considered by the writer as probably the deeper-seated equivalents of the basal rhyolite of the Great Basin section, are evidently younger than and at times intrusive into a great body of biotite-hornblende quartz-monzonite. A similar hornblende-biotite quartz-monzonite was found east of the Walker River Range, in Gabb's

Reasoning on the basis of the deductions specified, we may speculate briefly concerning the cause of the two revolutions, the reappearance of the intermediate magma, and the exhaustion of the old, highly differentiated magmas. In explanation of this, the hypothesis may be advanced that magma basins or lava reservoirs may be almost entirely exhausted by the expulsion of lavas to the surface, and that this emptying may permit refilling by new material from lower regions.[1] It is very possible that the processes of differentiation can only go on under certain circumstances, such as are probably afforded by the comparatively quiet magma basins, and that in the lower regions there may be so much mixing that segregation is impossible.[2] Therefore, when the magma basin is exhausted and receives a new supply from below, it is of material similar to that which filled the basin before differentiation altered it. It is probable that in this way the history of many petrographic provinces, when closely studied far back into geologic time, will be found to be not a simple, single process, but a succession of several or many differentiation cycles, some of which will probably be found to be complete, and some interrupted by this or that accident. It is probable that the existence of recurrent lavas will be found true at many points.[3] In Alaska the writer has found that the

Valley, and here was considered to be extrusive. The writer's grounds for considering that the Walker River Range granite is equivalent to the basal rhyolite cannot be given in this paper, but will appear subsequently. If they prove sound, then the older monzonite very likely represents a pre-rhyolitic monzonitic effusive rock, or at least a less siliceous pre-rhyolite magma.

[1] Since writing the above the writer has chanced upon the following sentence of IDDINGS ("Origin of Igneous Rocks:" Bull. Phil. Soc., Washington, Vol. XII, 1892–4, p. 179): "It is also possible to find a recurrence of different varieties at one center of eruption, which may be accounted for by supposing successive supplies of magma from some depth, which differentiate into similar varieties before their final eruption," He also finds that the same idea had been previously expressed by Sir Archibald Geikie (Quar. Jour. Geol. Soc., London, Vol. XLVIII, 1892, p. 178), as follows: "And as the successive protrusions took place within the same circumscribed region, it is evident that in some way or other, during the long interval between the two periods, the internal magma was renewed as regards its constitution, so that when eruptions again occurred they once more began with basic and ended with acid materials."

[2] IDDINGS (op. cit., p. 196) considers that the general or undifferentiated magma remains undifferentiated on account of being solid, that is, being in a state of potential liquidity.

[3] GEIKIE (op. cit.) in his study of the history of volcanic activity in Great Britain

probably Silurian basalt or basaltic diabase of the Rampart series is identical in composition with the olivine-basalts of the Pliocene.[1] Yet between these two periods a great variety of volcanic rocks, including other basalts, appeared in Alaska.

In studying the succession of lavas it must be borne in mind that the processes of differentiation are quite independent of the causes which produce the expulsion of lavas. Therefore, while the differentiation in a magma basin may go on so that all intermediate types between the initial intermediate one and the final extremes are represented, yet the causes producing eruption will probably occur only at different points in this process, so that the record will be only partial and perhaps not to be interpreted except by comparison with other localities. For this reason, the observed succession must be studied with regard to its general aspects rather than to its details. In interpreting the succession, also, the possibility, or even probability, of many intermediate forms being brought about by accidental mixing during the general processes of differentiation, must be borne in mind. This error may be eliminated if at each period of vulcanism we select the extreme important types, omitting the associated intermediate ones as possibly formed by mingling. The variations introduced by mingling and those brought about by irregular volcanic eruptions are such that it is difficult to apply to them any law. It has been assumed, for example, that in general basalts overlie rhyolites where these occur close together. This is held by Messrs. Hague and Iddings[2] as well as by previous observers. But Marvine[3] observed, in the Colorado River region, basalt lying upon rhyolite, and the present writer observed the same relation in the Pleistocene lavas of Meadow Valley canyon, which is a part of the drainage of the Colorado.

J. E. SPURR.

from the earliest pre-Cambrian times to the Tertiary, has found that similar rocks recur at many different points in the succession. He finds also similar series, so that he is led to divide the whole succession into natural groups or periods of volcanic activity. See also IDDINGS, op. cit., pp. 145, 179, 196.

[1] Geology of the Yukon Gold District. Eighteenth Ann. Rept., U. S. Geol. Surv., Part III, Economic Geology, p. 241.

[2] Mon. U. S. Geol. Surv., Vol. XX, p. 86.

[3] U. S. Geol. Surv., W. 100th Mer., Part III, p. 205.

THE GLACIER OF MT. ARAPAHOE, COLORADO

On the fourth day of August 1900, I was one of a party of seven men who ascended Mt. Arapahoe. This mountain is the highest of a small group of peaks on the Continental divide in Colorado. It is situated about latitude 40° 1′ N. and longitude 105° 38′ W.[1] and has an elevation of 13,520 feet above sea level. There are several peaks of nearly equal altitude in the group, but they are so intimately connected that they form practically one mountain. The group is locally known as "The Arapahoes." The peaks, together with their spurs and connecting ridges, nearly encircle a large enclosure in which the north branch of Boulder Creek rises. In the southern part of this enclosure is a well-defined cirque which is partitioned off by a spur extending into the enclosure from the side of the highest peak. This spur forms the north wall of the cirque. Its west and south walls are formed by Arapahoe Peak proper and the peak next south, together with their connecting ridge, which is but little lower than the summit of the peaks. The east wall is formed by a third peak, the summit of which is a few hundred feet lower than the other two and joined to the peak on the south side by a moderately high ridge. The cirque opens toward the northeast by a constricted passage into Boulder Creek valley.

The inner slopes of the cirque are precipitous on all sides. In only a few places can they be climbed in safety. The accompanying photograph, Fig. 1, taken from a high point and looking downward, does not adequately represent the degree of slope. The south wall is, in places, nearly vertical. The naked cliffs rise something like 1000 feet in the clear. But at the southwest and west sides the slopes are such that great masses of snow and ice of unknown depth lie upon them, reaching from the main mass at the bottom of the cirque, to the top of the ridge. The largest of these arms is shown in

[1] Hayden's atlas of Colorado.

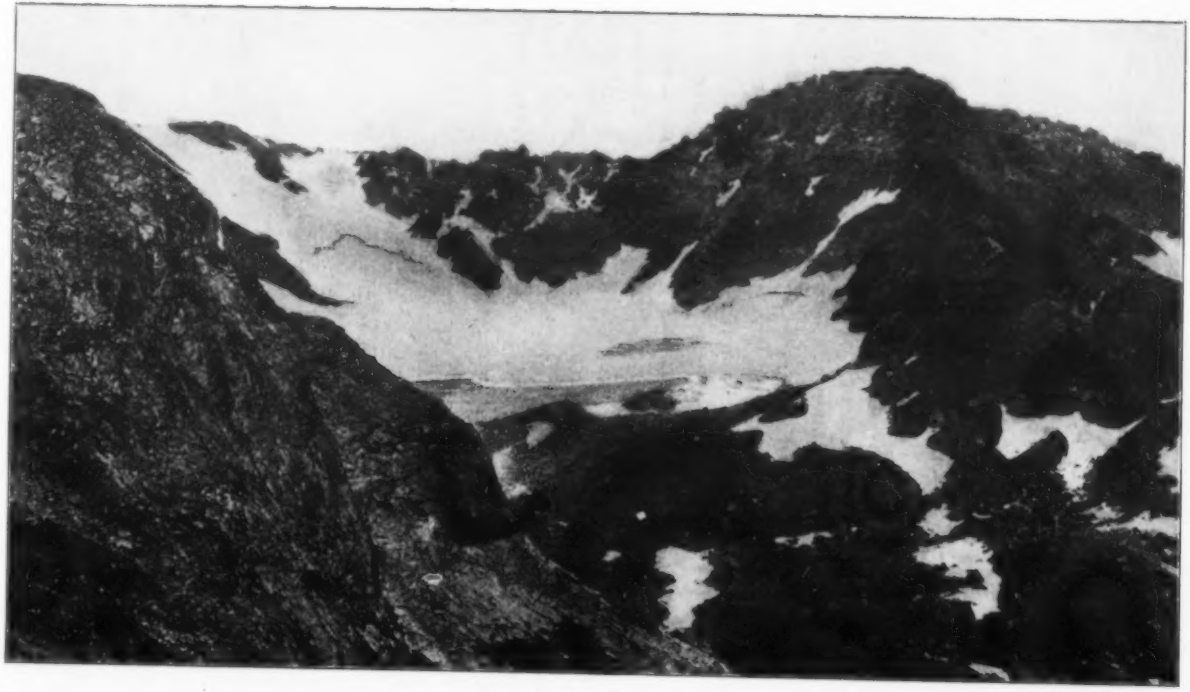


FIG. 1.—View of the Arapahoe glacier from below.

the illustration Fig. 1. The peak with its perpendicular cliffs forming the south wall, together with about one third of the cirque, is cut off from view by the bluff in the foreground. Figure 2 is a near view of this peak showing the upper extremity of one of these arms of snow and ice.

The cirque presents exceptional advantages for the accumulation and preservation of snow and ice:

1. The encircling peaks and ridges are barriers behind which the drifting snow accumulates during the winter. From whatever direction the wind blows, except from the northeast, its velocity is checked by the peaks and ridges forming the walls of the cirque, and the cirque receives its burden of snow. The importance of this mode of accumulation is well illustrated in the long snow drifts which are common along the high ridges throughout the mountains where the winds have dropped their burden in the lee of the crests. In some instances the summer's heat is not sufficient to melt away these drifts even where they lie exposed to the sun on the south side of the ridges.

2. The snow and ice of the cirque are more or less protected from the heat of the sun, by the elevated rim which is highest, and the inner slope steepest, on the south and west sides. On these two sides where the slope is gentle enough to permit it, lie accumulations of snow and ice of unknown thickness, extending from bottom to top of the walls. On the northern side, *i. e.*, the southern slope of the spur, the snow and ice reach but a little way up the side. This may be due in some measure to a difference in the amount of accumulation of snow, but it is certainly due primarily to the greater melting power of the sun on the slope facing southward.

3. The snow and ice of the cirque are also protected by sheltering from the east, south, and west winds. While our party was on one of the peaks overlooking the cirque, a thunder storm from the southwest enveloped the mountain. After the wind had swept the clouds from the southwestern side of the mountain, the cirque remained full of thick mist. The wind which was blowing at a moderately high rate of speed, cut off

FIG. 2.—The south peak of the Arapahoes, showing the upper extremity of one of the smaller arms of the glacier.

the cloud mass even with the crests of the ridges, and passed completely over the cirque instead of descending into it in any notable measure, and sweeping the mist away. For nearly half an hour after the clouds had been swept away from the windward slope of the mountains, the cirque was more or less obscured by shifting and eddying mists. These were at first parts of the original cloud. Later they were mists formed within the cirque. The latter formed the better index to the action of the winds. From their behavior it was evident that only secondary air currents came in actual contact with the snow and ice of the cirque.

Within the cirque the snow and ice are nearly all collected into two masses. These seem to be essentially independent of each other, and are separated by a ridge of débris. To the east of this ridge is the smaller of the two. To the west of the ridge is the larger—the main mass of snow and ice of the cirque. The larger field was estimated to be nearly two miles wide. Its length seemed to be approximately the same but I was not in a position to make a satisfactory estimate of the length. Its surface is steeply inclined. In several places where the snow and ice extends to the top of the south wall, we measured the inclination of its surface from above as carefully as possible by holding one climbing staff vertically and sighting down the slope with another. The angle thus given showed an inclination of about fifty degrees. At these points the upper edge which had been melted back at its contact with the cliffs, showed a thickness of twenty to forty feet. Over the bottom of the cirque the slope of the surface of the ice is gentle enough for small bowlders from the cliffs above to lodge on it. This gentler slope was somewhat thickly covered in places with stones and small bowlders. No large bowlders were seen on the surface, but below the lower edge of the ice, are great numbers of rock-masses, ten to twenty feet in diameter or even larger. It is probable that the large bowlders gain momentum enough on the steep slopes above to carry them over the gentler slopes and beyond the edge of the ice

The ice is hard and compact to the surface. Bowlders weighing two hundred or three hundred pounds were rolled down the slopes but made little impression on the surface of the ice. A small lake fifteen feet across and four feet deep was found on the surface. Late in the afternoon I found that the ice had softened scarcely enough during the day to prevent me from slipping even on comparatively gentle slopes.

The mountaineers who are familiar with the Arapahoes, had warned us against descending over the ice on account of crevasses. An opening seen about five hundred feet below the top of the ridge and which appears as a broken line in the illustration (Fig. 1) is presumably a crevasse. Others were seen from a distance which were not so well defined. I had no opportunity for close inspection. The mountaineers gave me somewhat careful descriptions of the openings, and told of a man who had been lost presumably in a crevasse. Their search for him resulted in finding nothing but his overcoat. From the descriptions given by these men, and from what I saw of the snow and ice, I am convinced that true crevasses are to be found there.

The stratified nature of the ice is seen along the steep face of its lower edge. Dark bands, probably due to the accumulation of foreign material on the surface during the summer, alternate with lighter bands. Some of the individual bands were traced, with the aid of the field glass, for long distances. Only the uppermost of these bands can be distinguished in the accompanying photograph. This is seen as a light line along the upper edge of the face of the ice, and is due to the whiteness of last winter's snow. On the surface of the ice at the right and a little way back from the edge, is a dark spot where the fresh white snow has been removed from the darkened surface of an older accumulation.

Along the base of the eastern rim of the cirque, a relatively small amount of snow and ice accumulates to form the smaller field. Its tendency to movement indicated by the slope of its surface, is diagonally opposed to that of the greater mass moving from the west and south. Over the surface of this smaller

mass I descended for about a mile but discovered no unquestioned evidences of movement of the ice. Between this and the edge of the greater mass to the west, a large ridge of débris has been formed. The ridge is inconspicuous at its inception near the upper end of the smaller ice field, but farther down it increases in size until near the outlet of the cirque it assumes notable proportions. In former times the upper part of this ridge now separating the two snow fields, was probably a medial moraine. But the recession of the ice has changed it into a terminal moraine throughout the greater part of its length. The ridge is crescent shaped and conforms rather closely to the edge of the ice. It has two more or less distinct crests — an outer large one, and an inner small one. Between the smaller crest and the edge of the ice, is a well defined trough.

There is a shallow lake a short distance below the edge of the ice. From an eminence on which I stood looking down upon this lake, I noticed that the current, produced by the stream flowing into it from the ice above, could be plainly traced for several rods by its whiteness which was presumably due to the rock flour derived from the ice above. This was not present in sufficient quantity to attract my attention in the running stream. But the contrast in color as the whitened water of the stream entered the green water of the lake was conspicuous. Closer inspection strengthened the conclusion that the stream carried rock flour.

The size of the ice mass; its great though unknown depth; the steep inclination of its surface; its stratification and crevasses; its terminal moraine; and the rock flour of its stream, all point to the inference that this field of snow and ice constitutes a true glacier.

The valley into which the cirque opens is one of broad bottom and precipitous sides. The side walls are nearly vertical in many places. Its floor is occupied by a chain of lakes interrupted in several places by groups of poorly formed roches moutonnées. Most of the lakes are in rock-hewn basins, but some are formed back of débris dams. One in particular, near

the head of the valley, is a beautiful example of the latter. It rests behind a crescent shaped ridge—a comparatively recent terminal moraine. Fragments of terminal moraines extending partly across the valley bottom, occur in several places near the head of the valley.

Résumé.—1. The exceptional amount of snow and ice in the cirque at Mt. Arapahoe is due to the unusual advantages presented for its accumulation and preservation. These consist (*a*) in trapping the drifting snow, and (*b*) in protecting it from sun and warm winds. 2. Within the cirque are two fields of snow and ice which are essentially independent of each other at the present time. The larger field is estimated to be something like two miles in width and about the same in length. 3. The snow and ice of the larger field constitutes a glacier. This is attested (*a*) by the amount of snow and ice there accumulated, and by the inclination of its surface which varies from about 10° to 50°; (*b*) by its stratification indicated by the banding of the face; and (*c*) by its movement, indicated by the crevasses, the moraines, and the rock flour. 4. This glacier is the survivor of a much larger glacier which formally occupied the upper part of Boulder Creek valley.

WILLIS T. LEE.

THE SHENANDOAH LIMESTONE AND MARTINSBURG SHALE[1]

INTRODUCTION

WHILE engaged in fieldwork on the Maryland Geological Survey, the writer has had an opportunity to examine to some extent the upper part of the Shenandoah limestone and the overlying Martinsburg shales.

Shenandoah limestone.—The name Shenandoah was proposed by Mr. Darton in 1892 for the limestones of the Shenandoah Valley and the formation was described in the vicinity of Staunton, Va., as consisting of "a great mass of impure magnesian limestones below, grading upwards through a series of cherty beds of no great thickness into several hundred feet of light-colored, heavily bedded purer limestones. The lower beds were not found to be fossiliferous. In the cherty beds only a few middle Ordovician gasteropods were found. . . . . The upper member is sparingly fossiliferous at many localities with a middle to upper Ordovician fauna in which the forms *Orthis occidentalis*, *O. testudinaria*, *Leptæna alternata*, and *Chætetes lycoperdon* were predominant. *Pleurotomaria subconica*, *Conularia trentonensis*, *Platynotus trentonensis*, and several others were also noted."[2]

Mr. Darton in his account of this formation in the Staunton folio described an upper member of the limestone from 200 to 350 feet in thickness which is said to be purer, more thickly bedded and generally of lighter color than the older part of the formation. It is also stated that in the upper division "fossils occur also in greater or less profusion throughout its course. The fauna is that of the Trenton limestones of New York."[3]

Martinsburg is near the northwestern corner of the Harper's Ferry sheet which was mapped by Mr. Arthur Keith,[4] and the

[1] Published by permission of Dr. Wm. Bullock Clark, State Geologist of Maryland.

[2] Amer. Geol., Vol. X, p. 13. [3] Geologic Atlas of the U. S., Folio 14, 1894, p. 2.

[4] Geologic Atlas of the U. S., Folio 10, 1894.

line between the Shenandoah limestone and the Martinsburg shale is clearly shown in the vicinity of that city, but the description of the formation gives no additional information regarding its age.

Professor Wm. B. Rogers considered that the Trenton, Utica and Hudson River formations were represented in the Potomac Valley at Williamsport and to the west; but he apparently regarded the greater part of the limestone as of Chazy, Levis and Calciferous age.[1]

Martinsburg Shale.—The name Martinsburg shale, like that of the Shenandoah limestone, was proposed by Mr. Darton from the exposures near Martinsburg, W. Va., "a region in which," he states, "the formation is extensively and typically exposed." It is stated that at the base there is "a thin series of alternating thin bedded limestones and slates" but for the most part the rocks of the formation "are slates and shales, mainly of dark color. . . . . The beds are fossiliferous at many points; graptolites are found in the basel beds, notably in some light colored weathered shales in cuts of the Chesapeake and Ohio Railway, two miles east of Staunton and further east; along the Little North Mountain, and in the Warm Spring, Crab Bottom and other anticlinal valleys westward, remains of upper Ordovician brachiopoda are moderately abundant. The forms most frequently met with are *Leptæna sericea*, *L. alternata*, *Orthis testudinaria*, *O. pectinella*, and *Modiolopsis modiolaria*. The precise equivalency of the formation is not known, but judging from its general relations and fauna it probably comprises the Utica, Hudson River and possibly small amounts of adjacent formations of the New York series. It is the No. III of Rogers' reports and has generally been called 'Hudson River.'"[2]

Under the description of the formation in the Staunton Folio Mr. Darton states that "In the Jack Mountain exposures fossils are abundant, and the species are of Hudson age," while "In the

[1] See Plate No. VII, Sec. No. 1, in "A Reprint of Annual Reports and other papers of the Geology of the Virginias," edited by Jed. Hotchkiss, 1884.

[2] Amer. Geol., Vol. X, pp. 13, 14.

beds east of Churchville and in the buff and red slates at the base of the formation in cuts two miles east of Staunton, Utica graptolites occur in considerable abundance."[1]

Mr. Keith, apparently, did not have a very clear conception of the lithological character of this formation for he states in his description that "It consists of black and gray calcareous and

FIG. 1.—Parson's quarry in Shenandoah limestone, near Martinsburg, W. Va.

argillaceous shales of fine grain, and shows no variations within this area."[2] It will be seen in the following description that after the thin argillaceous shales in the lower part of the formation there are shales alternating with greenish micaceous sandstones. Again there is confusion in reference to the period to which the formation belongs for in the description it appears under the Cambrian,[3] and under the "columnar section"[4] and legend of the map as Silurian.

[1] Geologic Atlas of the U. S., Folio 14, p. 2.

[2] Geologic Atlas of the U. S., Folio 10, p. 3. [3] *Ibid.*, p. 3. [4] *Ibid.*, p. 5.

DESCRIPTION OF SECTIONS

What follows in this paper in reference to the Shenandoah limestone relates more particularly to the upper part of that formation which was studied to some extent in the vicinity of Martinsburg, West Virginia, and Pinesburg, Maryland.

Limestone and shale near Martinsburg.— 1. Along the Baltimore and Ohio Railroad immediately east of Martinsburg station are exposures of the upper part of the Shenandoah limestone. At the western end of the cut, just east of the railroad bridge over Tuscarora Creek, are dark blue, fairly massive limestones, some of which, however, on weathering split into quite thin, irregular layers (Fig. 1). These limestones are fossiliferous, two species of *Lingula*, together with some other forms having been noticed, and the rocks closely resemble many parts of the typical Trenton limestone of New York. In the eastern part of this cut, near the switchtender's station, there are thin layers of dark blue limestone which alternate with dark blue to black calcareous shales containing fragments of graptolites, and this part of the cut shows a transition from the massive limestones of the Upper Shenandoah to the lower shales of the Martinsburg formation. This part of the section is shown in Fig. 2.

3. To the east of the switch cut the rocks are covered for some distance; but about one half mile east of the station is Cemetery cut, where several hundred feet of quite thin, even, bluish, somewhat argillaceous shales are well shown. These may be seen in Fig. 3. In a rather hasty examination no fossils were found and the lithological character of these shales is rather more like that of the Hudson in New York than the Utica shale.

4. To the east of Cemetery cut is a covered space and then another railroad cut in shale follows. These shales which are mainly blue and arenaceous closely resemble lithologically the Hudson shales of the Mohawk Valley and Eastern New York, and alternating with them are thin layers of greenish, micaceous sandstone similar to those in the lower part of the Hudson in

numerous localities in New York. In the western part of the cut are some rather thin, blackish, argillaceous shales.

In the southern part of Martinsburg, operated by the Maryland Limestone Quarry Company, are extensive quarries in the massive Shenandoah limestone, large quantities of which are

FIG. 2.—Transition from Shenandoah limestone to Martinsburg shale in switch cut on B. & O. R. R. east of Martinsburg, W. Va. The men are standing opposite the upper part of the Shenandoah limestone and the Martinsburg shale is to the right.

shipped to the steel and other furnaces in the vicinity of Pittsburg. The limestone is mainly a light colored drab and this part is reported as the purest and best for flux. No fossils were found in the limited time given to the search and one of the quarrymen said he had never noticed any.

Exposures near Pinesburg, Md.— A number of the exposures in the vicinity of Pinesburg station on the Western Maryland

Railroad in the southern part of Maryland, about thirteen miles north of Martinsburg, proved more fossiliferous than those in the vicinity of Martinsburg.

1. The Pinesburg quarry is on the Western Maryland Railroad, a short distance west of the station. There is an exposure of about fifty feet, the southern and higher part of the quarry furnishing dimension stone which is dark blue to almost black in color with banded layers of blue and bluish-gray and contains fragments of trilobites, crinoid stems and some other fossils, while the northern and lower part is used mainly for ballast. The dip is 20° E. A view of this quarry is given in Fig. 4.

2. A short distance to the east of the quarry is an excavation in massive drab limestone, some of which before weathering is dark in color, but afterward it is all a light gray. Fossils are rare. Several specimens of *Leperditia*, a *Rhynchonella*, a fragment of a *Leptæna* similar to *alternata* and fragments of some other fossils were found.

3. On the railroad, between the quarry and the station, is a small cut through thin bedded, dark blue, compact limestones and some shaly layers. Fossils are common in some of these layers and on one a large number of poorly preserved and crushed specimens of *Asaphus platycephalus* Stokes were found. The complete list of species found in this cut is as follows:

1. *Asaphus platycephalus* Stokes.
2. *Monticulipora* (*Prasopora*) *lycoperdon* (Say).
3. *Calymene callicephala* Green (?).
4. *Lingula rectilateralis* Emm. (?).
5. *Plectambonites sericea* (Sowb.).
6. *Orthis* (*Dalmanella*) *testudinaria* Dal.
7. *Rhynchotrema inæquivalve* (Castelnau) (?).

The rock has been quite badly crushed, but in lithological appearance it closely resembles the Trenton limestone in New York. This limestone ledge is near the top of the Shenandoah formation, for the Martinsburg shales occur only a short distance to the east by the side of the road at the Pinesburg station

and to the east of "Slate Ridge." The weathered shale is a gray to an olive-grayish color and is very argillaceous. It is to be noted that the lower shales of the Martinsburg are argillaceous and calcareous, while the arenaceous ones finally alternating with

FIG. 3.—Martinsburg (Utica) shale in Cemetery cut, on B. & O. R. R., one half mile east of Martinsburg, W. Va.

sandstones, occur higher in the formation. This part of the formation, composed mainly of thin bedded, micaceous, somewhat buff-colored sandstones, alternating with some olive argillaceous and arenaceous shales, may be seen by the side of the highway west of Williamsport, Md., and in the western part of the town.

CONCLUSIONS

The fauna found in the railroad cut at Pinesburg is composed of species which are of common occurrence in the Trenton limestone of New York, and the lithological appearance of the rock is that of typical thin-bedded exposures of that limestone. There seems no question but that the upper part of the Shenandoah

FIG. 4.—Shenandoah limestone in the Pinesburg quarry west of Pinesburg, Md.

limestone is correctly correlated with the Trenton limestone. The lower part of the Shenandoah limestone contains Cambrian fossils; but the line of division between the Cambrian and Lower Silurian, which apparently is not indicated by any physical break, has not yet been determined in the Great Valley. It is hoped that future work in Maryland or West Virginia may give us more definite information concerning the composition and limits of this great limestone formation. The bluish to black calcareous and very argillaceous shales which succeed the Shenandoah limestone and form the lower part of the Martinsburg

shales closely resemble the Utica shale, and represent that formation.

In that lithological change from the argillo-calcareous shale, the arenaceous deposits of the succeeding portion of the Martinsburg formation agree with the transition from the Utica to the Hudson shales of New York. This arenaceous part of the Martinsburg shale the writer would correlate with the Hudson shales of New York as exposed in the lower Mohawk Valley and the Helderberg region. In the revised list proposed by Clarke and Schuchert for the New York series,[1] Lorraine beds is probably the name of the formation with which these shales should be correlated. It is to be noted, however, that the deposits which have been called the Hudson formation in the Mohawk and Helderberg region do not contain many of the species, or resemble closely in lithological appearance the rocks in the vicinity of Lorraine, New York.

CHARLES S. PROSSER.

COLUMBUS, O.

[1] Science, N. S., Vol. X, 1899, p. 876.

Reviews

Geology of the Little Belt Mountains, Montana, with notes on the Mineral Deposits of the Neihart, Barker, Yogo, and other Districts, by Walter Harvey Weed, accompanied by a report on *The Petrography of the Igneous Rocks of the District*, by L. V. Pirsson. Twentieth Annual Report of the U. S. Geological Survey, Washington, 1900. Pp. 257–581, with 42 plates and 43 figures.

This voluminous report is based upon field work done in September 1893, and August 1894. The major part of the report was written by Mr. Weed, who describes the position, topography, and geological structure of the region. The rock formations are described in succession from the gneisses, schists, and Algonkian series, through Cambrian and Siluro-Devonian to Carboniferous. The geology of the region is treated in detail, commencing with the southern part of the range, and followed by Judith area, the Yogo, Big Baldy Mountain, Wolf Butte, Taylor Peak, Barker, and Monarch districts, and finally the Neihart.

A chapter is devoted to the general geology, and deals first with the history of the region as interpreted from sedimentary rocks, showing that the same general conditions prevailed in this region as in the rest of the eastern part of the Rocky Mountain area of the state. The uplift of the Little Belt Mountain range is supposed to have been due to lateral compression, but the minor doming and faulting observed at all the larger mountain masses are due to igneous intrusions.

With the exception of Yogo Peak all the prominent mountain masses are formed of igneous rock, whose structural features show that they constitute a group of closely related forms, grading from typical laccoliths to those of plutonic plugs or bysmaliths. The largest of these bodies is exposed over an area of three by five miles, and is probably 3000 feet thick. With these are associated numerous intrusive sheets, but few dikes. There are besides several intrusive rocks not directly connected with the laccolithic bodies. The character and origin of these intrusions are discussed.

The concluding chapter of Mr. Weed's report contains notes on the ore deposits, under the heading: "The Ores, Veins, and Mines." The ores are chiefly those of silver, silver-lead, and gold. Sapphire mines occur in Fergus county, and are said to be the most valuable gem mines in the country. Deposits of limonite and hematite are found in a number of localities and will some day be developed economically.

The petrography of the igneous rocks by Professor Pirsson is a rather full account of the rocks, their mode of occurrence and field relations, texture, and microscopical characters, together with their chemical composition and the estimated quantitative mineral composition. It also considers the general petrology of the region, and closes with a discussion of magmas by graphic methods, and the absorption of sediments by magmas.

The rocks are subdivided into (*a*) granular non-porphyritic rocks, (*b*) acid feldspathic porphyries, (*c*) lamprophyres, (*d*) effusive rocks. In the first group are found representatives of syenites, monzonites, diorites, shonkinites, and aplites. Among the syenites is analcite-(nephelite) syenite, which, unfortunately, has not been analyzed chemically. Syenite, monzonite, and shonkinite occur together as differentiation products of one rock body at Yogo Peak. In the shonkinite the proportion between the dark and the light constituents is $\frac{5}{3}\frac{5}{5}$ — that is, the former preponderate. The second group contain representatives of granite, syenite, and diorite classes, and constitute the laccoliths and many of the intruded sheets. Among these rocks there are many transitional types, the transitions being, in several cases, of much more importance locally than the more commonly-known types. Further, these transitions occur not only in different masses, but often in the same mass. The third group includes minettes, which are rather common in this district, besides nephelite-minette, vogesite, and analcite-basalts. Among the minettes is a variolitic facies, the small varioles being spherulites of feldspar. Nephelite-minette is a new variety of rock belonging to the monchiquite-alnoite series of Rosenbusch. Analcite-basalts occur as dikes in several localities. In one case the rock is estimated to contain 49.5 per cent. of analcite, the remainder being pyroxene, olivine, and magnetite. A rock closely allied to analcite-basalt carries the sapphires mined in this region. The sapphires are considered as having resulted from the absorption of fragments of clay shale included in the magma at the time of its

eruption. The fourth group includes basalt, which occurs only in two localities, as extrusive lava.

In the chapter on general petrology of the region it is pointed out that the average composition of all the igneous rocks observed would be that of a moderately acid syenite approaching an acid monzonite in character. The rocks of the larger laccoliths present a somewhat striking similarity in chemical composition and texture. They are generally phanerocrystalline porphyries. They correspond to Rosenbusch's granite porphyritic dike rocks. In this region they are preeminently laccolithic rocks. Their more acidic character must be taken into consideration in this connection, for in other regions less acid rocks occurring in the form of laccoliths exhibit typical granular, nonporphyritic texture. Here, as in other mountain groups of laccolithic character in the Rocky Mountain region, the depths at which the magmas are intruded appear to have exerted no perceptible influence on their granularity. It is evident that chemical composition is an important factor in the production of rock textures.

Differentiation of igneous magmas and the formation of aplitic veins are discussed and the variation in the mineral composition of the rocks at Yogo Peak is expressed diagrammatically. The application of diagrammatic methods to the discussion of chemical variations among rocks of one district is considered with special reference to Yogo Peak and the surrounding region. A comparatively simple mathematical relationship is made out for the principal rocks of the region, which is the more surprising when the intricate nature of the chemical molecules of several of the rock-making minerals is considered. It is perfectly evident, as an abstract proposition, that the chemical composition of any rock is a mathematical function of the several component minerals, whose chemical molecules are more or less variable functions of a few chemical elements. From which it may be inferred that whatever the process by which differentiation of a magma takes place the resulting solutions or magmas will probably sustain a mathematically intricate functional relation to one another. In the present instance the approximate relations appear to be comparatively simple. It is to be noted, however, that the correspondences between observed and estimated composition presented by Professor Pirsson, as he himself remarks, are merely close approximations. They are, nevertheless, striking. With regard to the absorption of sediments by magmas, the study of the igneous rocks in the Little Belt

Mountains shows that there is no evidence in this region in favor of the theory of considerable absorption.

J. P. I.

Geological Survey of Canada. Annual Report of Mineral Statistics for 1898. By E. D. INGALL, Ottawa, 1890. 196 pp.

This report shows an increase of total production for the year covered of 34.89 per cent., a production per capita of $7.32. This is compared with a total increase for the United States of 10.61 per cent., and a per capita production of $9.38, the source of the latter statistics not being given. Compared with previous years, there is a steady and large increase. From a table of proportionate values it appears that gold produces more than one-third (35.63 per cent.) of the whole, leaving coal (21.27 per cent.) well in the rear, while the next on the list are silver (6.71 per cent.) and copper (5.52 per cent.) In the preceding year coal had stood at the head of the list, the change of places being due to the large output of gold from the Yukon.

The total estimated value of metallic and non-metallic products is $38,661,000. The numerous tables usually give the production for several years previous, and afford the means for comparative studies.

C.

On the Subdivisions of the Carboniferous System in Eastern Canada, with Special Reference to the Union and Riversdale Formations of Nova Scotia, Referred to the Devonian System by Some Canadian Geologists. By H. M. AMI, Trans. N. S. Inst. Sci., Vol. X, Session 1899–1900, 17 pp.

The precise scope of the paper is well indicated in the title. The argument proceeds essentially on paleontological lines, and the physical lines of evidence are essentially set aside. In this case these latter embrace unconformities as well as the character of the rocks. The paleontologic evidence embraces plants, crustaceans, insects, mollusks, and amphibia. These are thought to indicate an Eo-Carboniferous age for the Union and Riversdale formations, which have been referred by some Canadian geologists to the Devonian system. The

author's classification of the Carboniferous of Nova Scotia is summarized in the following table:

Formations		Northern areas	Southern areas	Order
Neo-Carboniferous	Cape John	Cape John Sandstones		XII
	Pictou	Pictou Freestones		XI
	Smelt Brook	Smelt Brook shales		X
	Small's Brook	Spirorbis limestones		IX
	New Glasgow	N. Glasgow conglomerates		VIII
		Coal Measures		VII
		Unconformity		
Meso-Carboniferous	Stellarton	Millstone grit	Millstone grit	VI
	Westville		Unconformity (?)	V
	Hopewell		Hopewell and Windsor	IV
	Windsor			III
		Unconformity		II
Eo-Carboniferous	Union		Union	I
	Riversdale		Riversdale	

T. C. C.

Transactions of the Australasian Institute of Mining Engineers, Vol. VI. Edited by A. S. KENYON, Sec., Melbourne, 1900; pp. 247.

The following papers make up the contents:

On Safety Appliances and Precautions Necessary in Mines. By J. R. Godfrey (with 17 figures).

Contacts. By W. H. Ferguson.

Some Notes on Dry Crushing. By N. F. White (with 10 figures).

Contouring on Mining Properties with the Aid of the Tachometer. By H. P. Seale (with 10 figures).

Diamond Mines and Alluvial Deposits, South Africa. By P. R. Day.

The Manufacture of Sulphuric Acid and its Use in Metallurgy. By W. H. Mawdsley (with 10 figures).

Mine Stores. By F. Danvers Power.

The Use of Electricity in Mining. By E. F. J. Holcombe Hewlett (with 1 figure).

Recent Publications

—American Institute of Mining Engineers, Transactions of. Vol. XXIX, February 1899, to September 1899, inclusive. New York City, 1900.

—Ami, Henry M. Sir John William Dawson, a Brief Biographical Sketch. Reprinted from the American Geologist, Minneapolis, Vol. XXVI, No. 1, for July 1900.

—Andrews, E. C., B.A. Report on the Hillgrove Gold Field. Dept. of Mines and Agriculture, Geol. Survey, New South Wales. Sydney, 1900.

—Bather, F. A. The Recapitulation Theory in Palæontology, and F. Bernard's "Éléments de Palæontologie," a Review. Reprinted from Natural Science, Vol. II, No. 14, April 1893.

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—Beyer, Samuel Walker. Geology of Hardin County. Reprinted from Iowa Geological Survey, Vol. X. Annual Report, 1899, pp. 245–313. Des Moines, 1900.

—Böckh, Hugo. Die Geologischen Verhältnisse der Umgebung von Nagy-Maros. Budapest, 1899.

Orca Semseyi, Eine neue Orca-Art, Aus dem Unteren Miocæn von Salgó-Tarjan. Budapest, 1899.

—Brown, H. Y. L. Report on the Gold Discovery at Tarcoola, the Enterprise Mine, the Earer Dam Tin Find, and the Mount Gunson Copper Mine, with Plan. Record of the Mines of South Australia. Prepared under the authority of the Hon. Laurence O'Loughlin, M. P., Minister of Mines. Adelaide, 1900.

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—Dunn, E. J. Notes on the Dwyka Coal Measures at Vereeniging, Transvaal, etc. From the Transactions of the Philosophical Society of South Africa; Vol. XI, Part I. March 1900.

—Grant, Ulysses Sherman. Contact Metamorphism of a Basic Igneous Rock. Bulletin of Geological Society of America, Vol. XI, pp. 503–510. Rochester, 1900.

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—HOPKINS, T. C. Cambro-Silurian Limonite Ores of Pa. Bulletin Geological Society of America, Vol. XI, pp. 475–502, Pl. 50. Rochester, 1900.

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—New York, Seventeenth Annal Report of State Geologist, for the year 1897. James Hall, State Geologist. New York and Albany, 1899.

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—North American Fauna, No. 19. Results of a Biological Reconnoissance of the Yukon River Region. (U. S. Department of Agriculture, Division of Biological Survey.) Washington, 1900.

—NUTTING, CHARLES CLEVELAND, Professor of Zoölogy, University of Iowa. American Hydroids. Part I. The Plumularidæ. Pls. 34. (Special Bulletin No. 4, Smithsonian Institution, U. S. National Museum.) Washington, 1900.

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Neue Bemerkungen zu den von A. Cathrein gegen mich gerichteten Angriffen.

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III. Multiplication of Rays and Bilateral Symmetry in the 20-Rayed Star-Fish *Pycnopodia Helianthoides* (Stimpson). By William E. Ritter and Gulielma R. Crocker. Vol. II, pp. 247–274.

IV. The Tree Willows of Alaska. By Frederick V. Coville. Vol. II, pp. 275–286.

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VI. The Bryozoa. By Alice Robertson. Vol. II, pp. 315–340.

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CORRECTIONS

1. In his review of Professor Davis' paper on "Glacial Erosion in France, Switzerland and Norway," in the last number of the JOURNAL, the reviewer said (p. 571): "If there is any reference in the paper to similar discordance between main valleys and tributaries not in any way connected with glacial erosion, it escaped the eye of the reviewer." Such reference occurred in the article, on page 283, lines 8–9, in the following words: "It should be noted that discordance of side and main valleys may also be found where a large river has lately been turned to a new path, as in the normal progress of the capture of the upper course of one river by the headward gnawing of the branch of another river (see reference to Russell below), or in the new arrangements of drainage lines in a region from which a glacial sheet has lately withdrawn." T. C. C.

2. In the article on "Methods of Studying Earthquakes," by Professor Davison, the words, "with a large number of observations—they are as a rule," on p. 305, opposite the middle of Fig. 1, should be transposed to the opposite page and inserted after the second line of the first complete paragraph, so as to read: "But the method of intensities does more than this. When the isoseismal lines are carefully drawn—and this is only possible with a large number of observations—they are as a rule roughly elliptical in form; their longer axes are parallel or nearly so, but they are not coincident."

In the eighth line of the same paragraph, "focus" should read "forms." C.